

OR 4,035,060

United State

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[54] ELECTRO-OPTIC DEVICE

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[73] Assignee: Dainippon Printing Co., Ltd, Tokyo, Japan

[*] Notice: The portion of the term of this patent subsequent to Mar. 16, 1993, has been disclaimed.

[21] Appl. No.: 631,706

[22] Filed: Nov. 13, 1975

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 399,481, Sept. 21, 1973, Pat. No. 3,944,330.

[51] Int. Cl.² G02F 1/13

[52] U.S. Cl. 350/160 LC

[58] Field of Search 350/160 LC; 340/336, 340/324 M, 324 R

[56]

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U.S. PATENT DOCUMENTS

| | | | |
|-----------|---------|---------------------|--------------|
| 3,774,195 | 11/1973 | Schulthess | 350/160 LC X |
| 3,820,875 | 6/1974 | Bohmer | 350/160 LC |
| 3,834,794 | 9/1974 | Soref | 350/160 LC |
| 3,944,330 | 3/1976 | Tsunoda et al. | 350/160 LC |

Primary Examiner—Edward S. Bauer

Assistant Examiner—Rolf Hille

Attorney, Agent, or Firm—D. Gordon Angus; Donald D. Mon

[57]

ABSTRACT

An electro-optic device comprises a plurality of first electrodes provided on a top substrate and a second electrode provided on a bottom substrate, the first electrodes confronting the second electrode through electro-optical matter which will show electro-optical phenomena by the application of electric field, the first and second electrodes being connected through external impedance elements such as resistors or capacitors to a variable voltage source. In this electro-optic device, the electric field applied between the first and second electrodes are partially changed by various means, for instance, by making the areas of the first electrodes different, or by varying the values of the external impedance elements such as resistors or capacitors, as a result of which the electro-optical matter shows various electro-optical phenomena.

11 Claims, 44 Drawing Figures

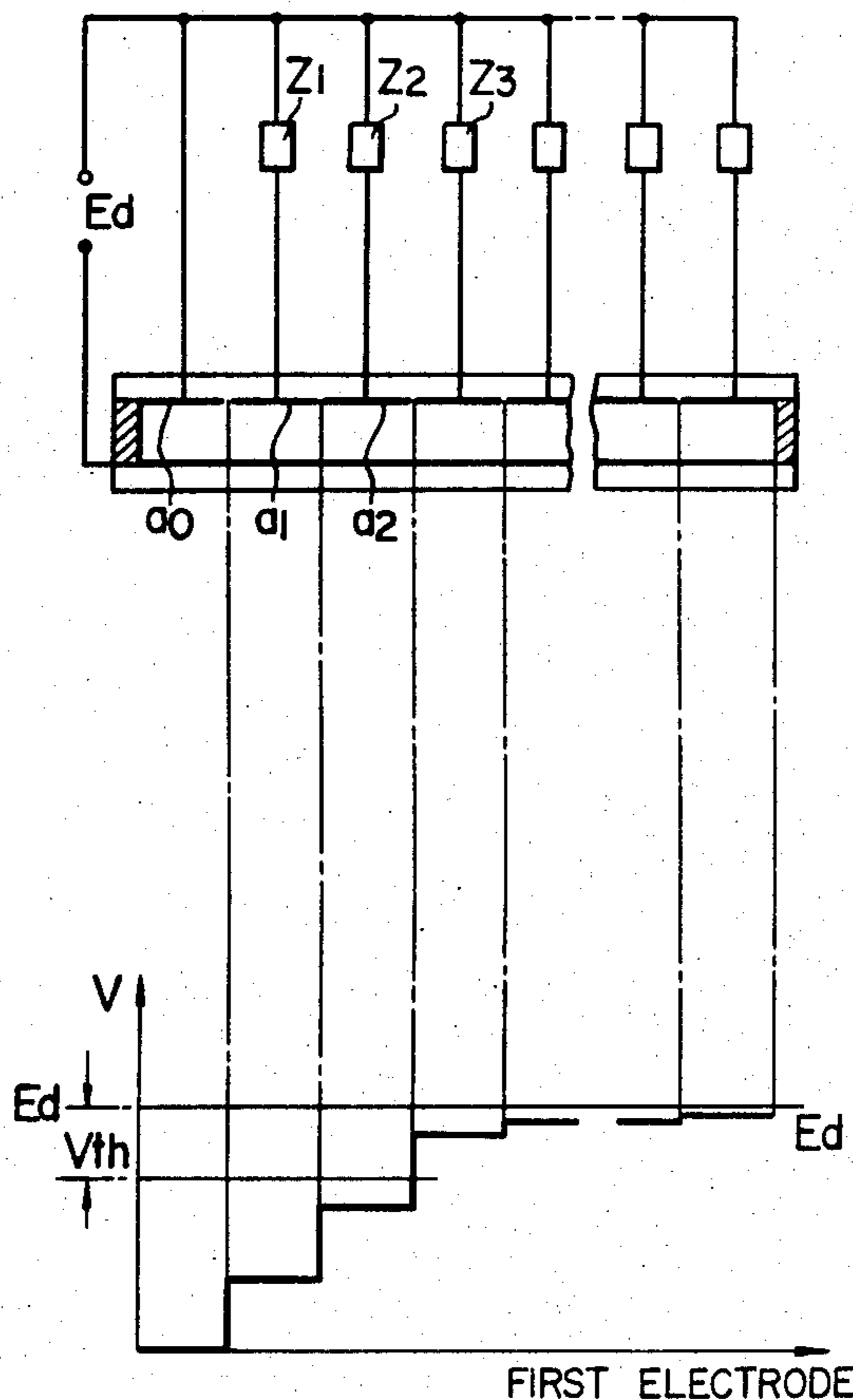


FIG. 1

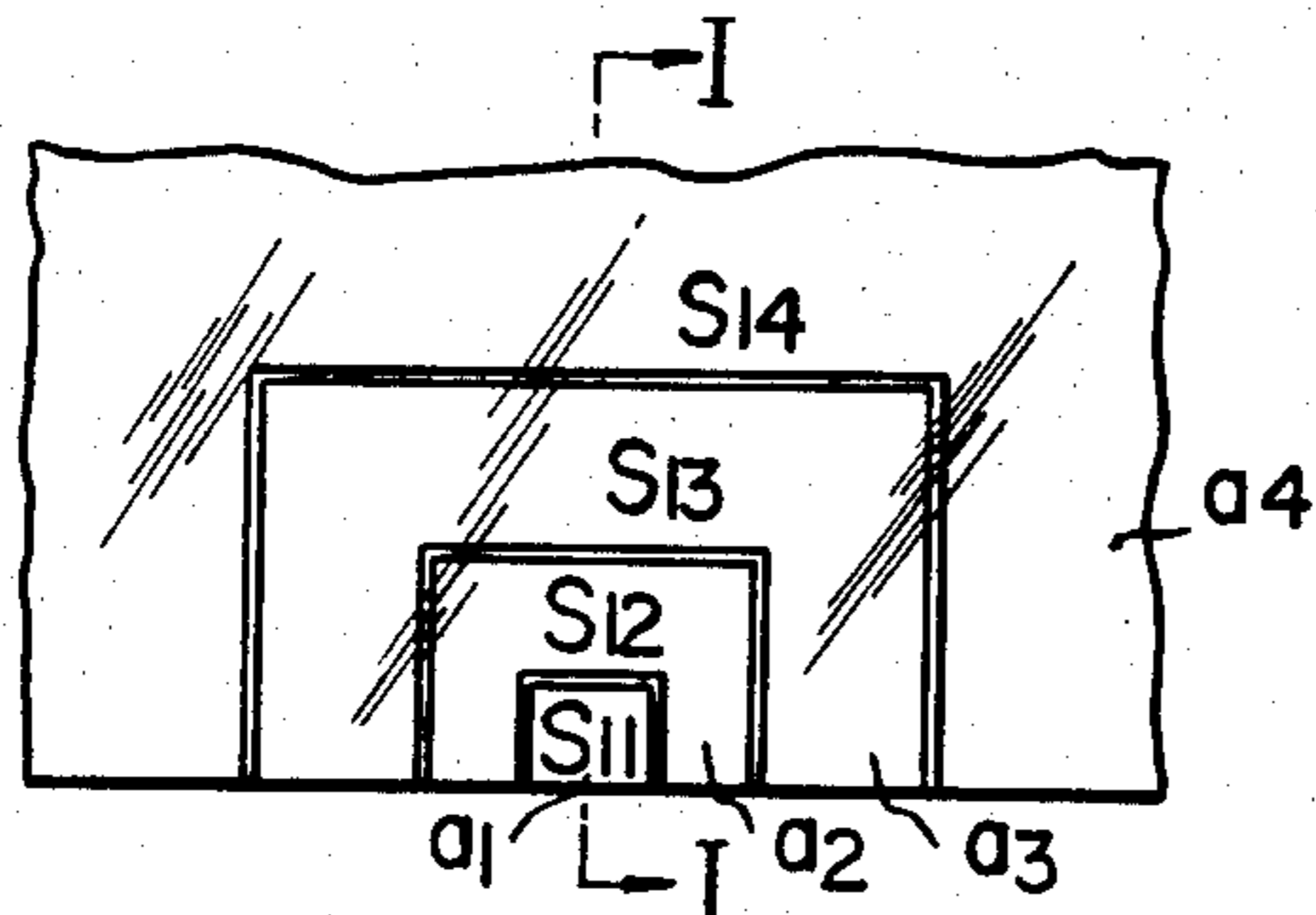


FIG. 2

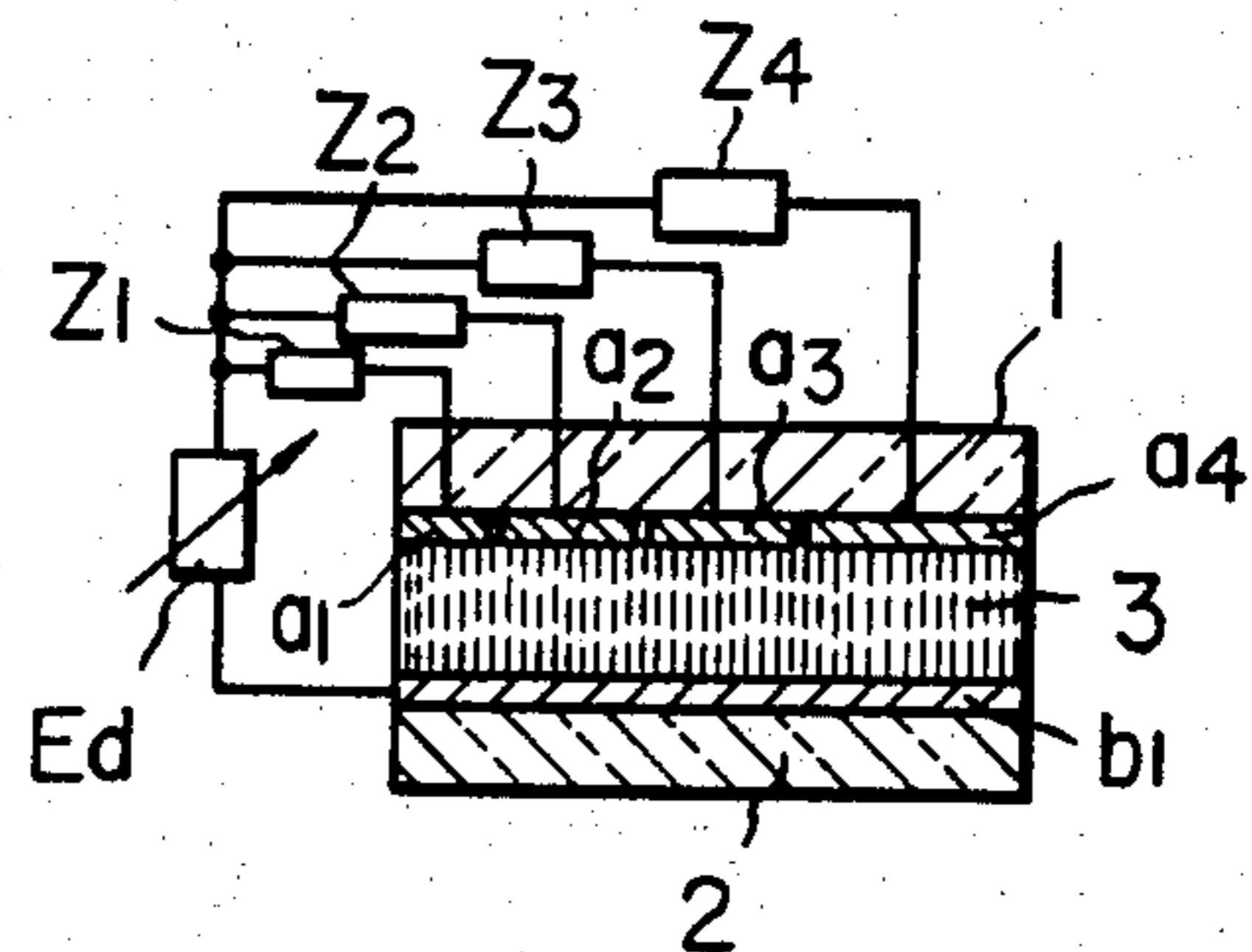


FIG. 3

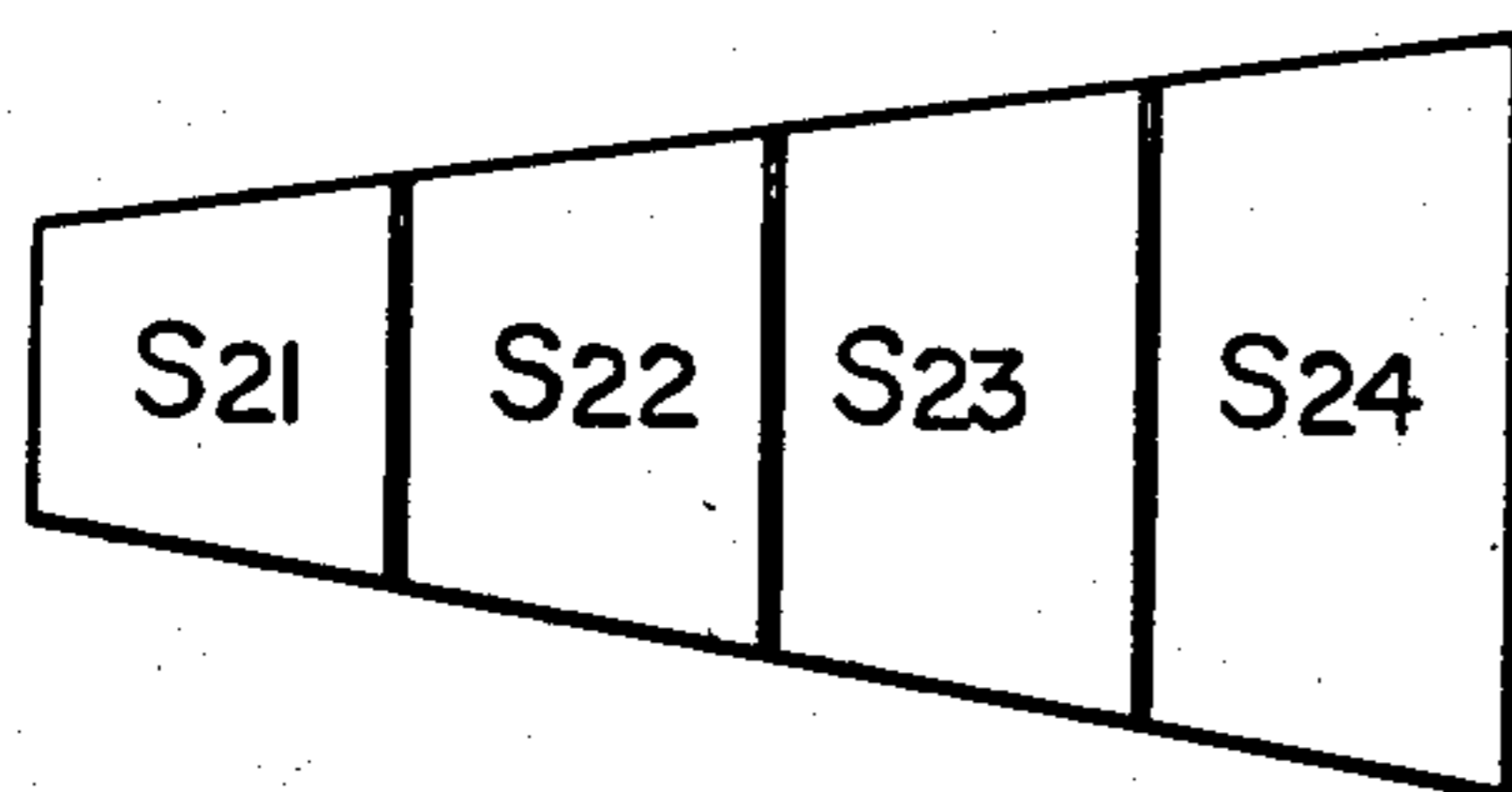


FIG. 4

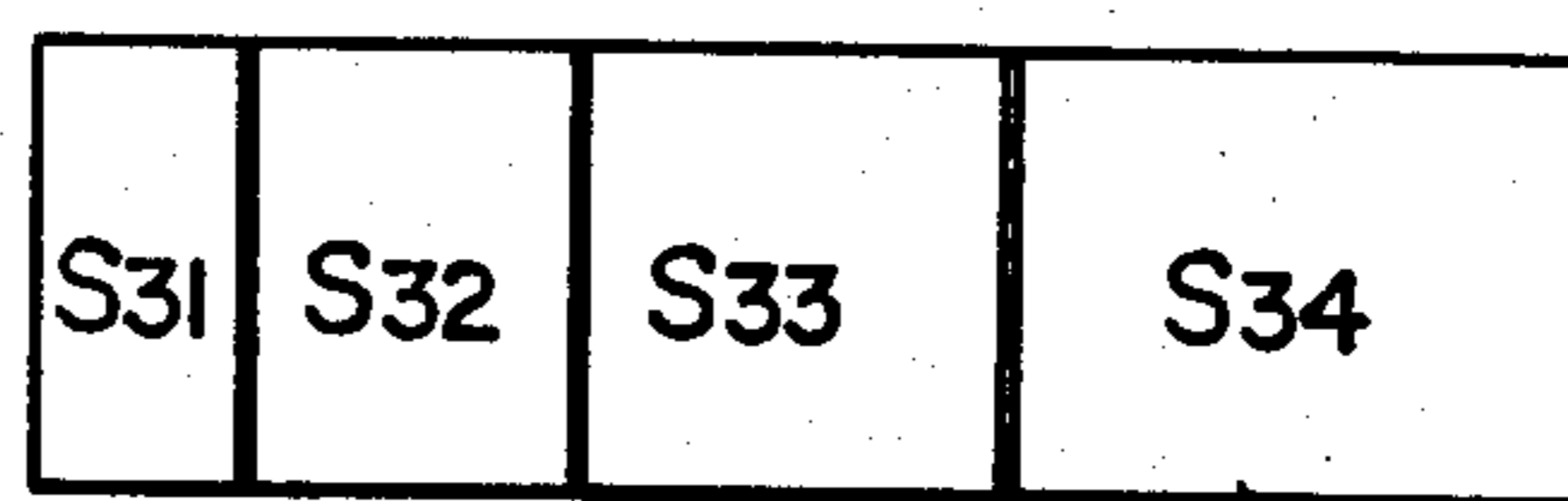


FIG. 5

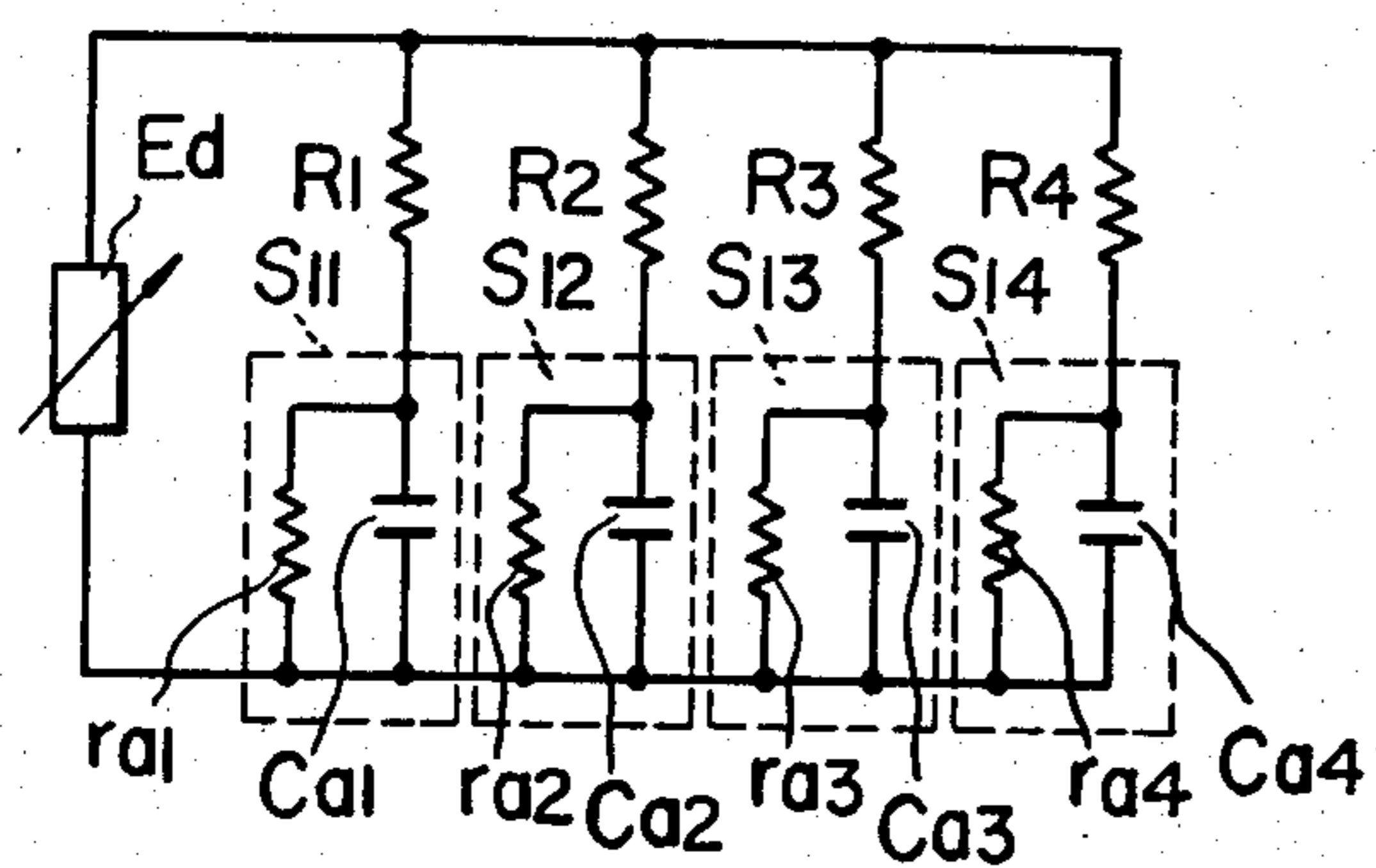


FIG. 6

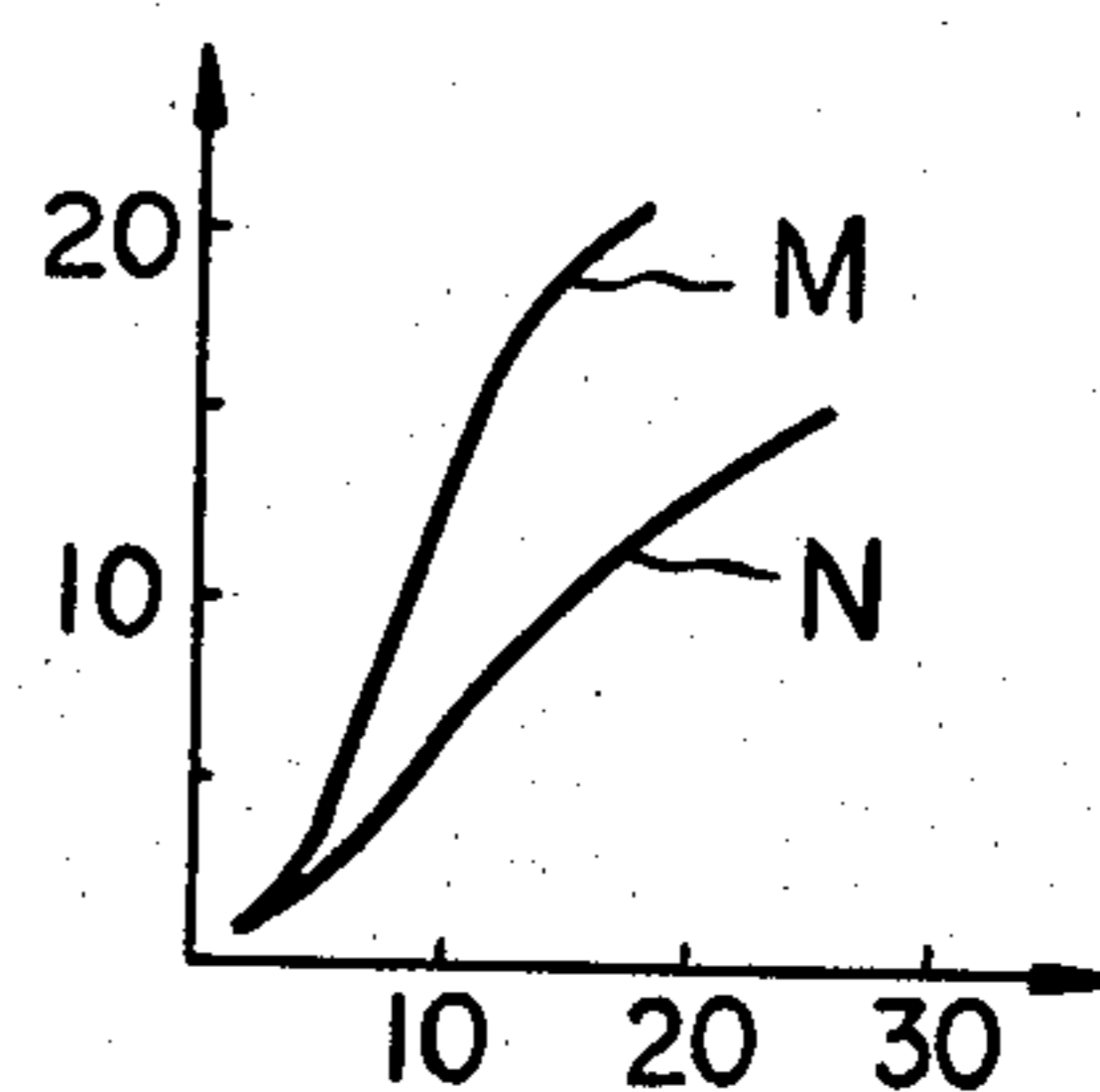


FIG. 7

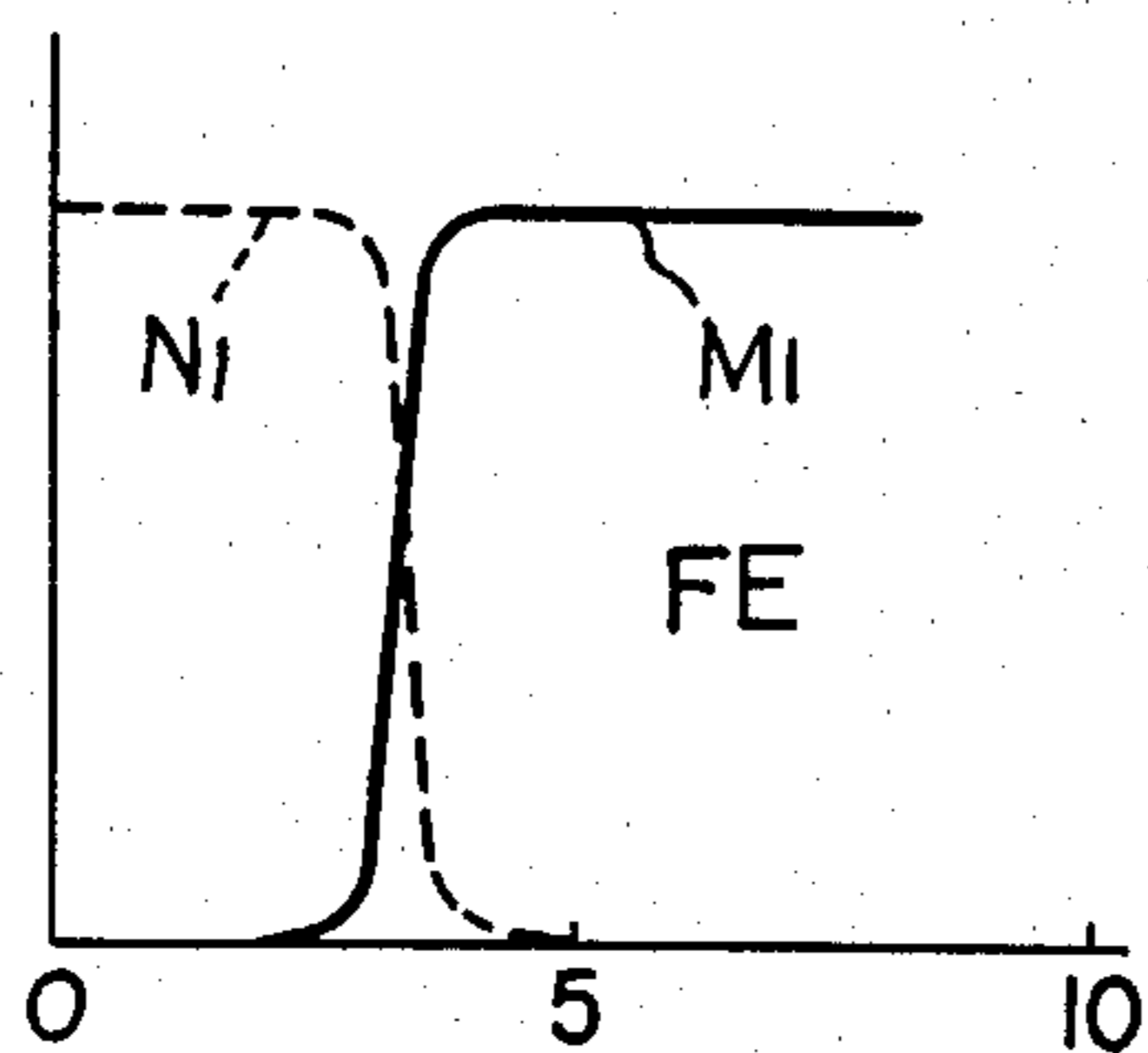


FIG. 8

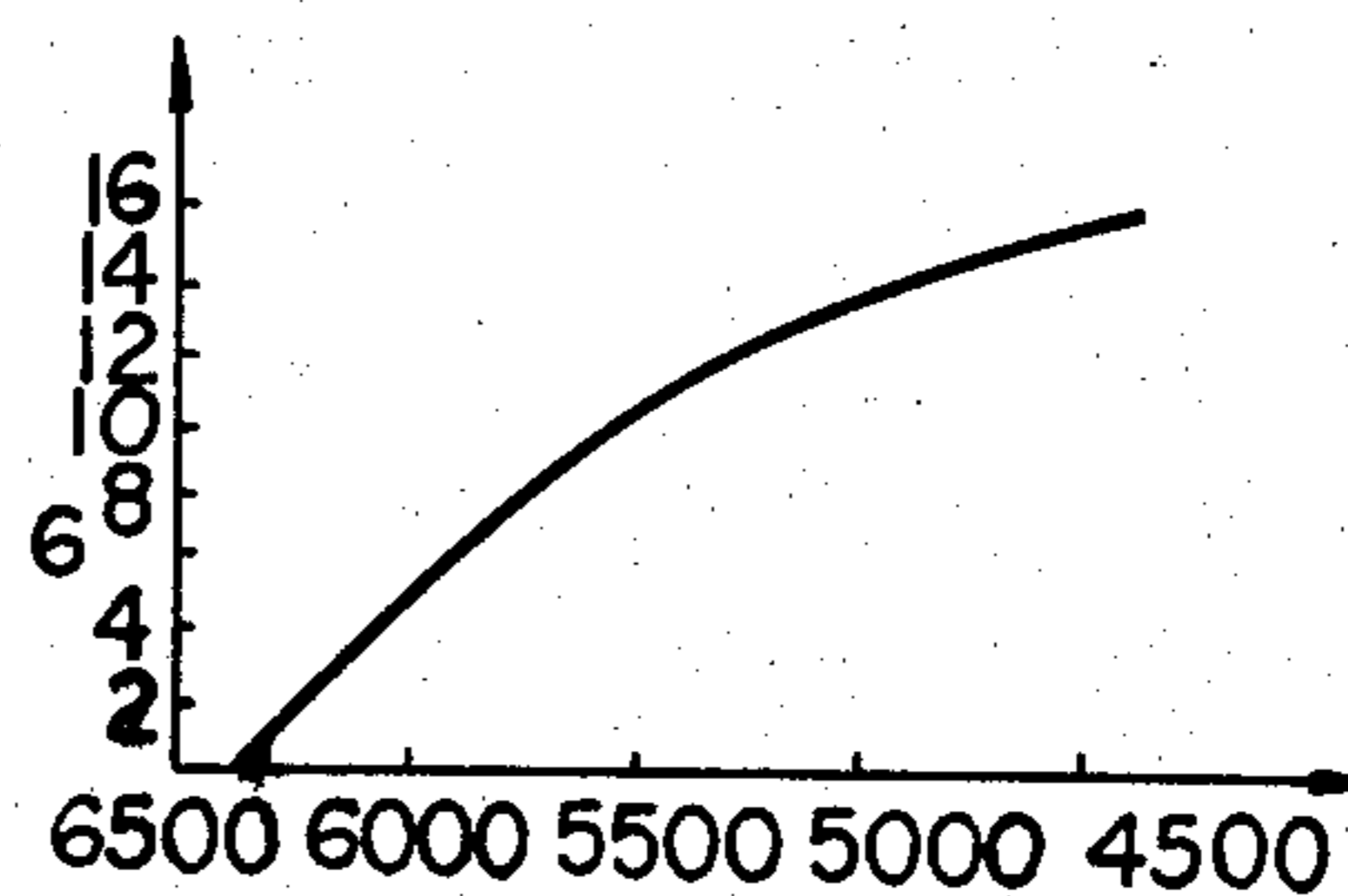


FIG. 9

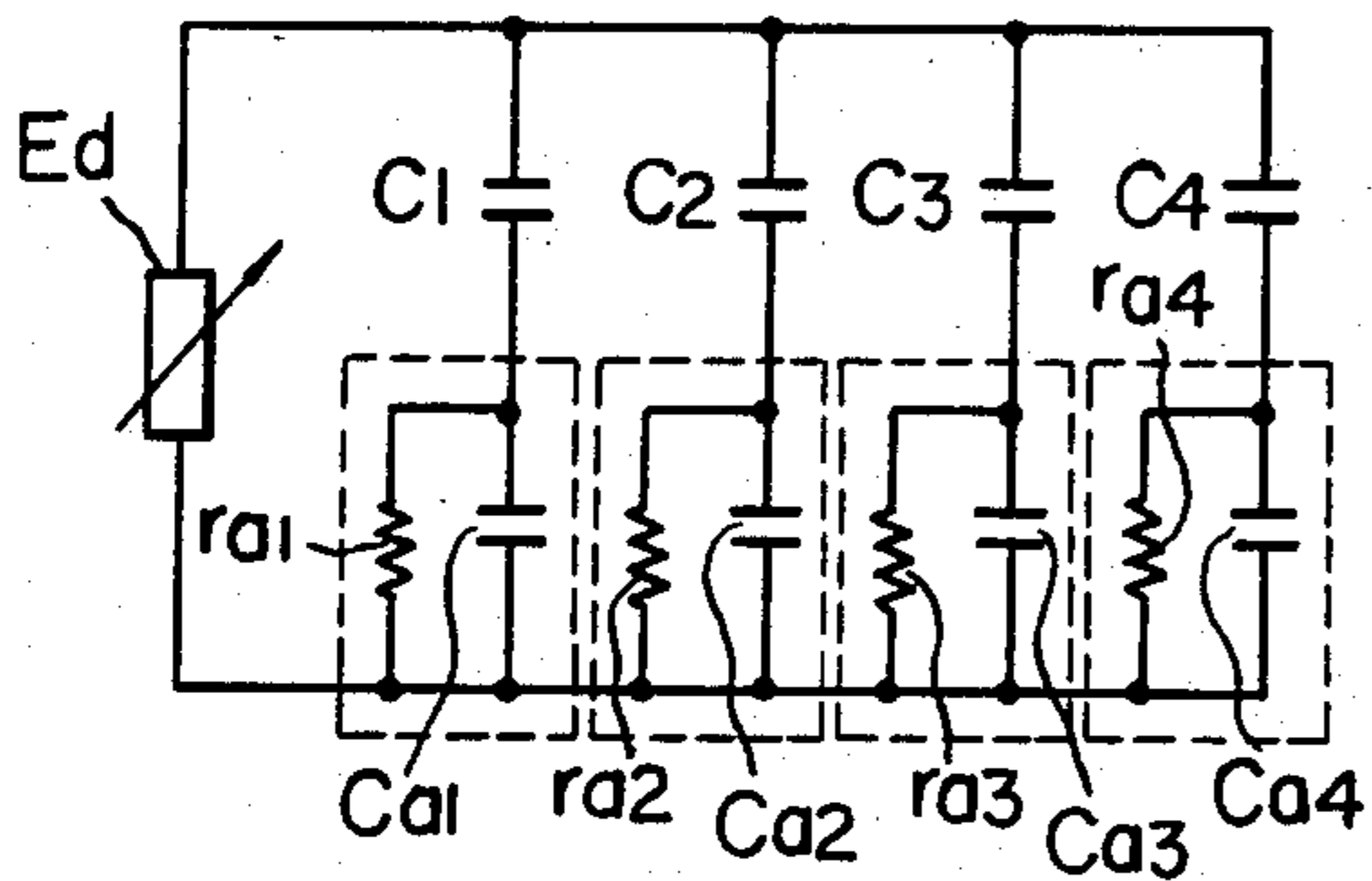


FIG. 10

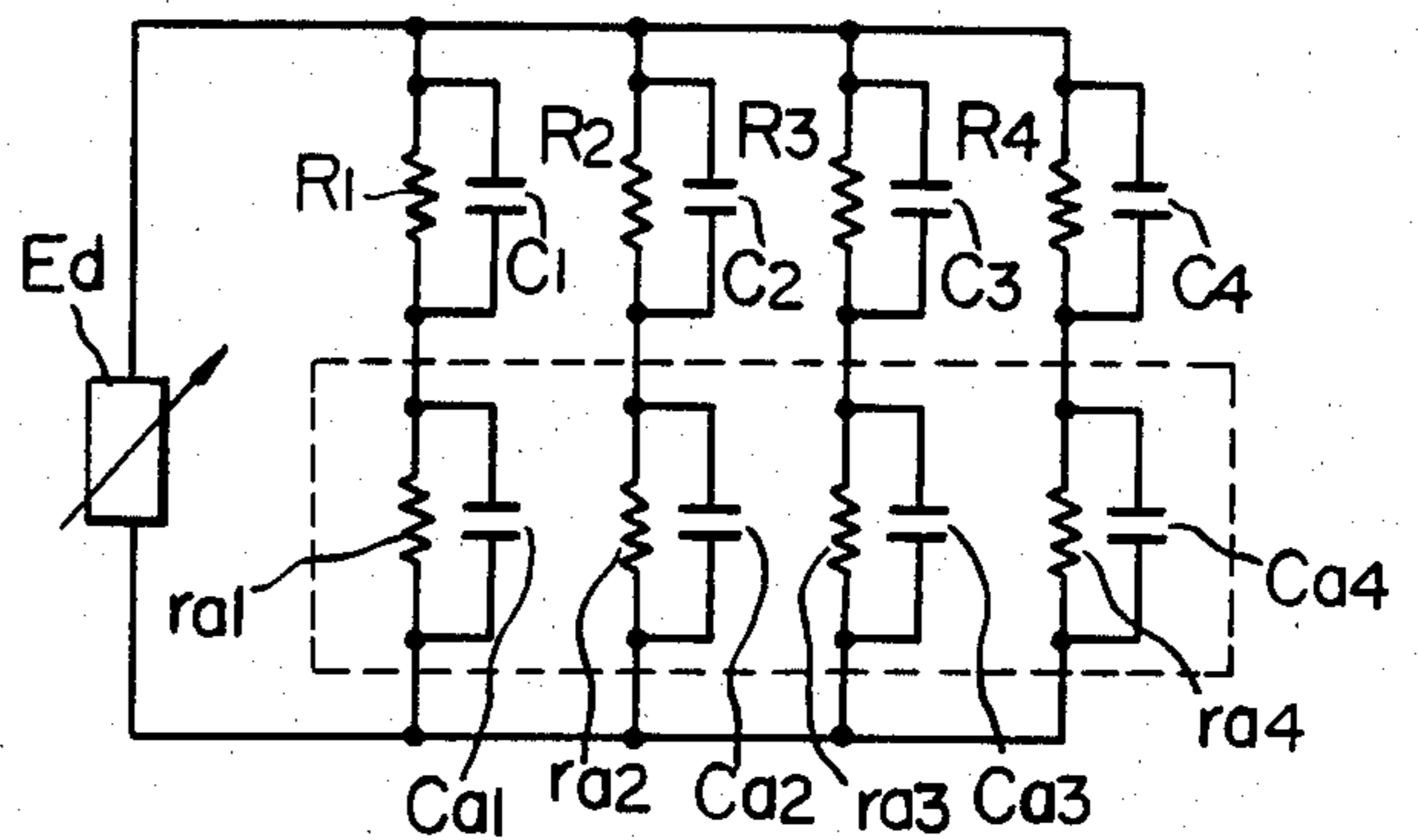


FIG. 11

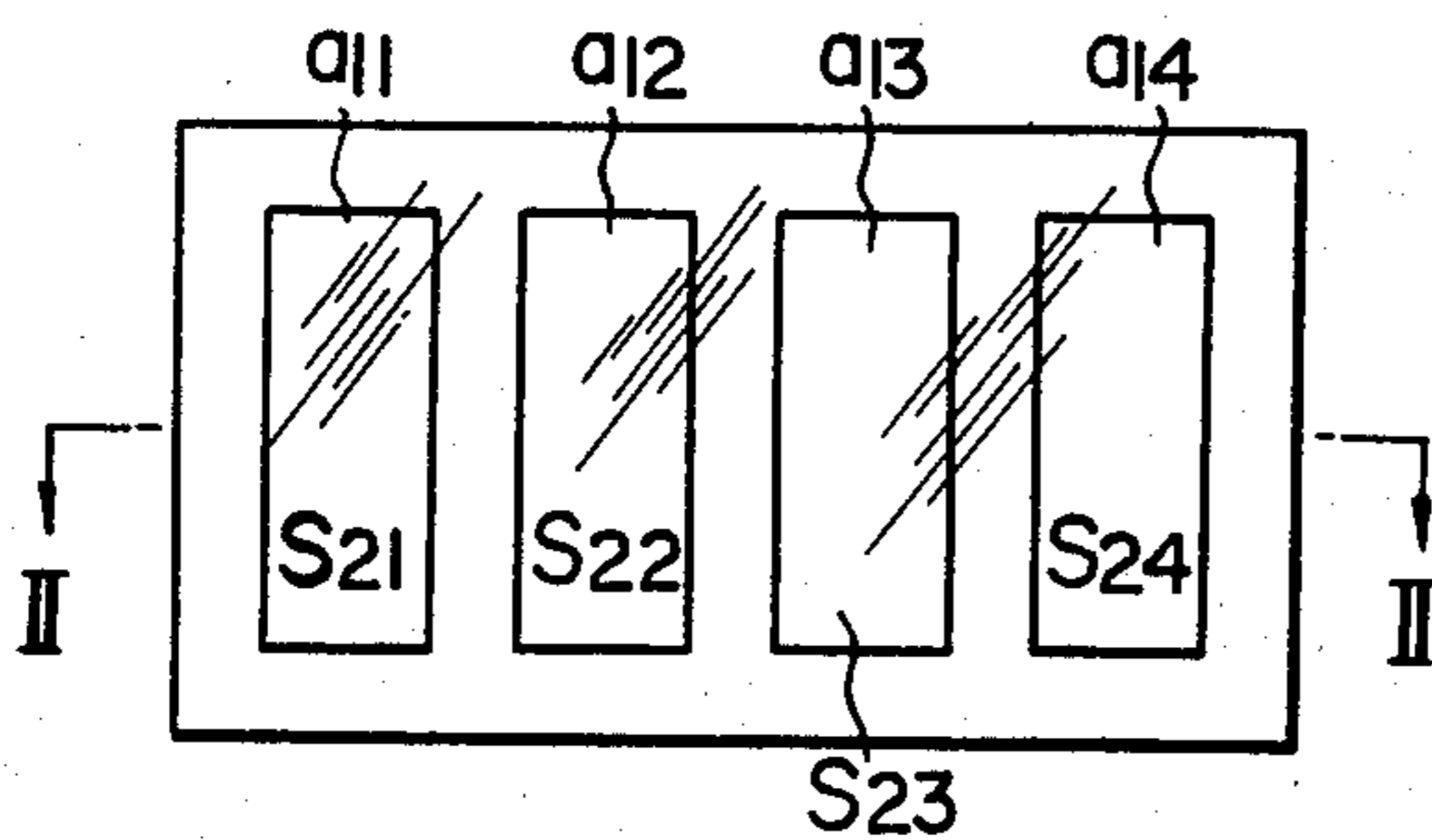


FIG. 12

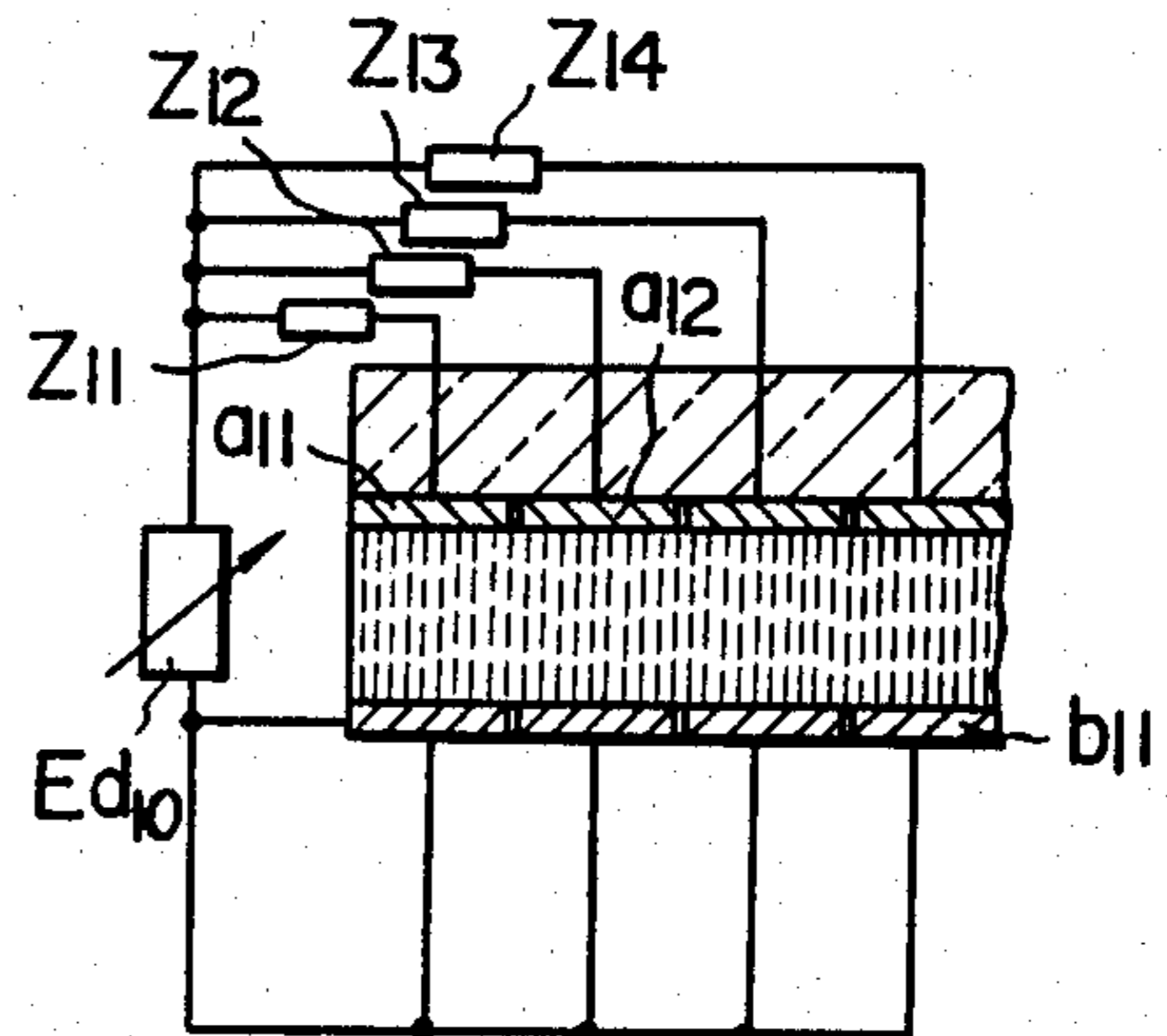


FIG. 13

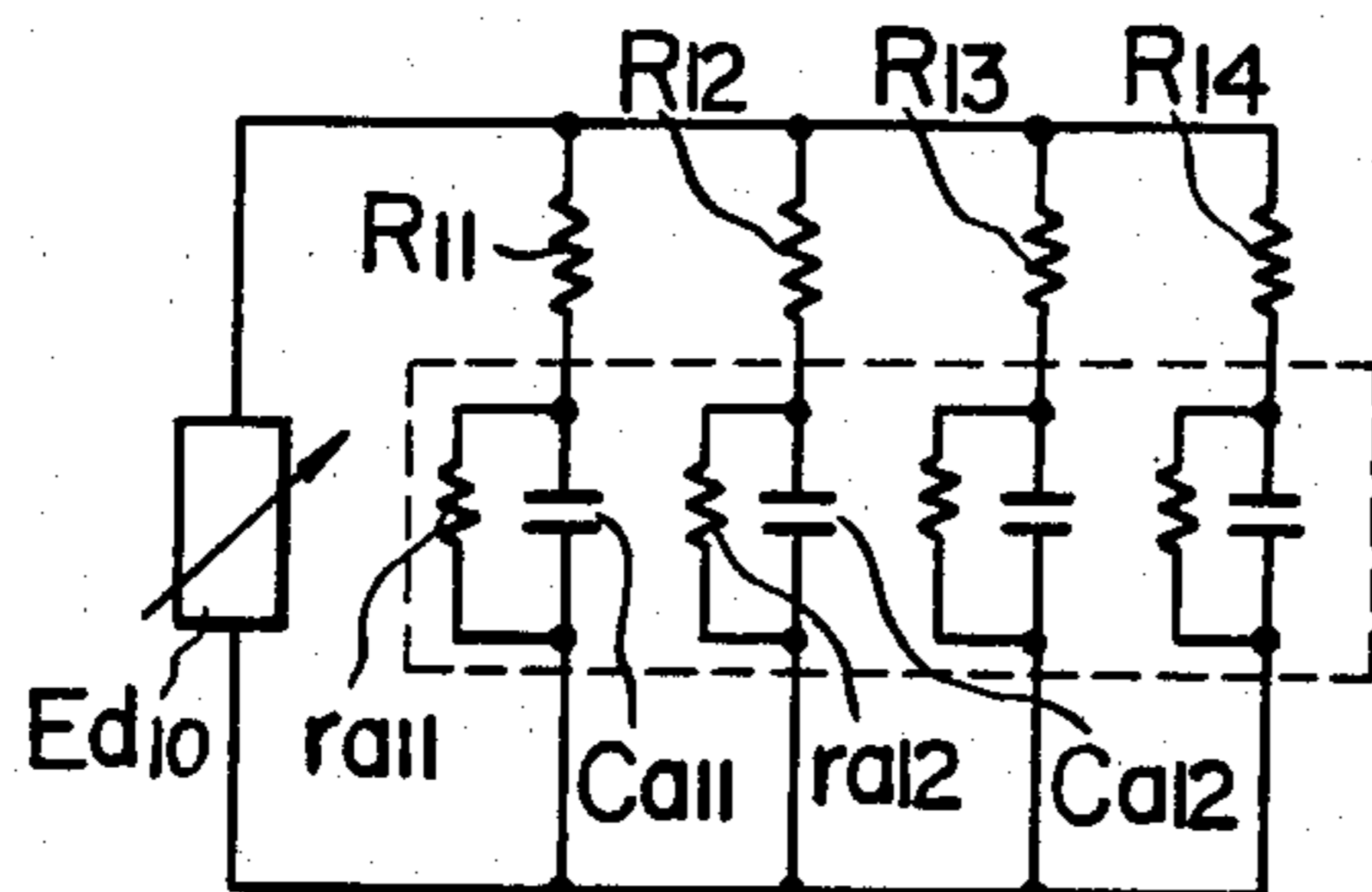


FIG. 14

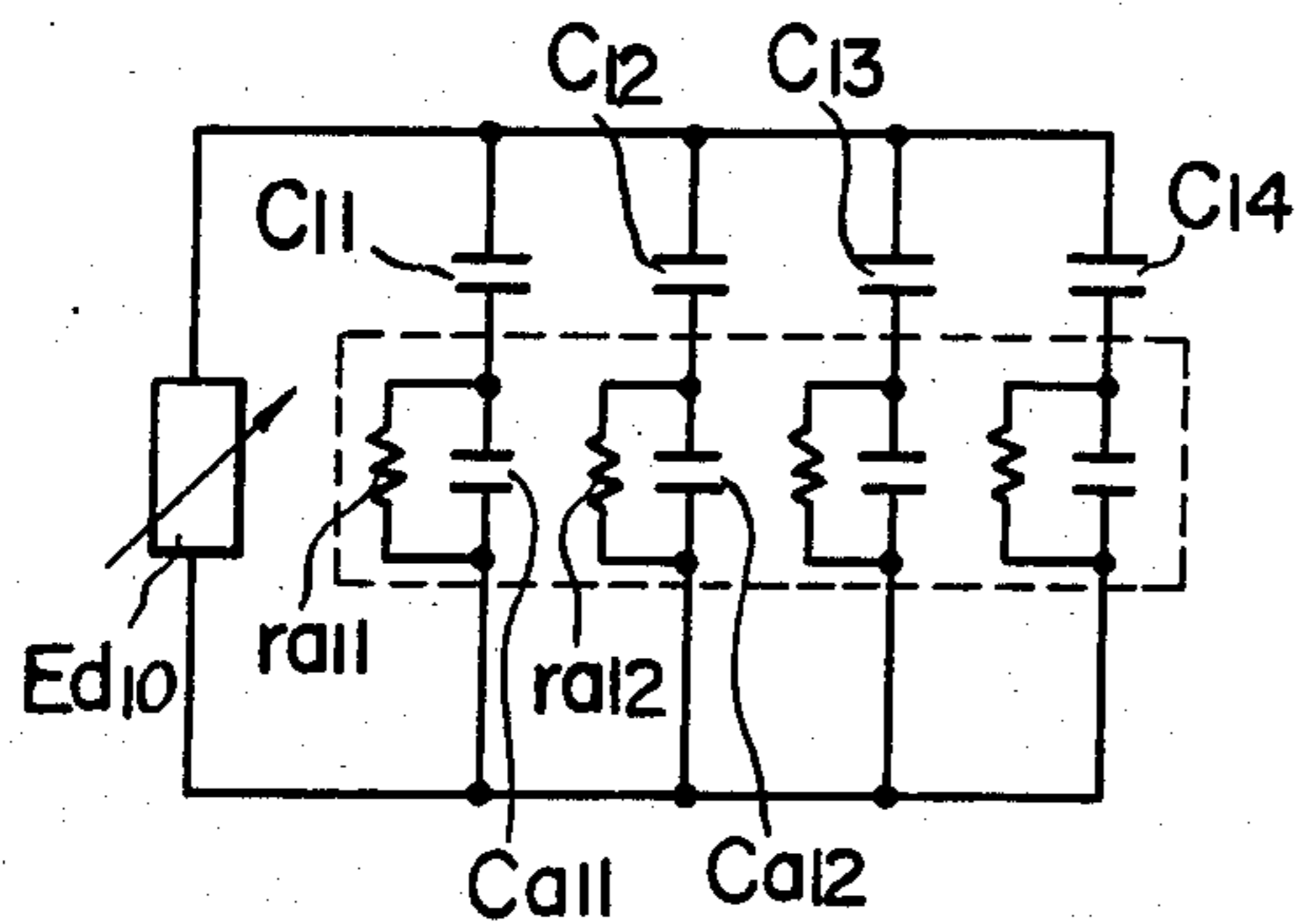


FIG. 15

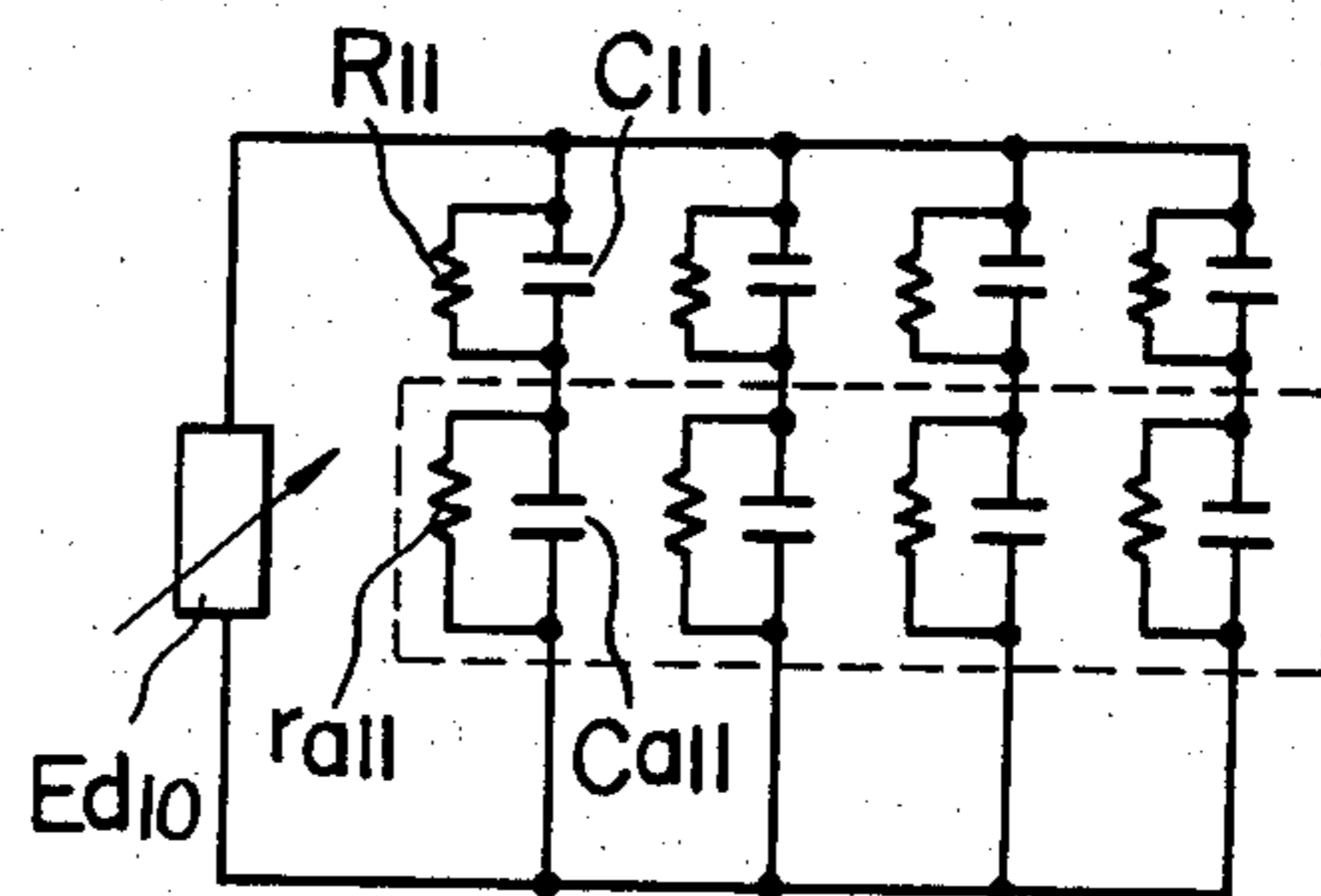


FIG. 16

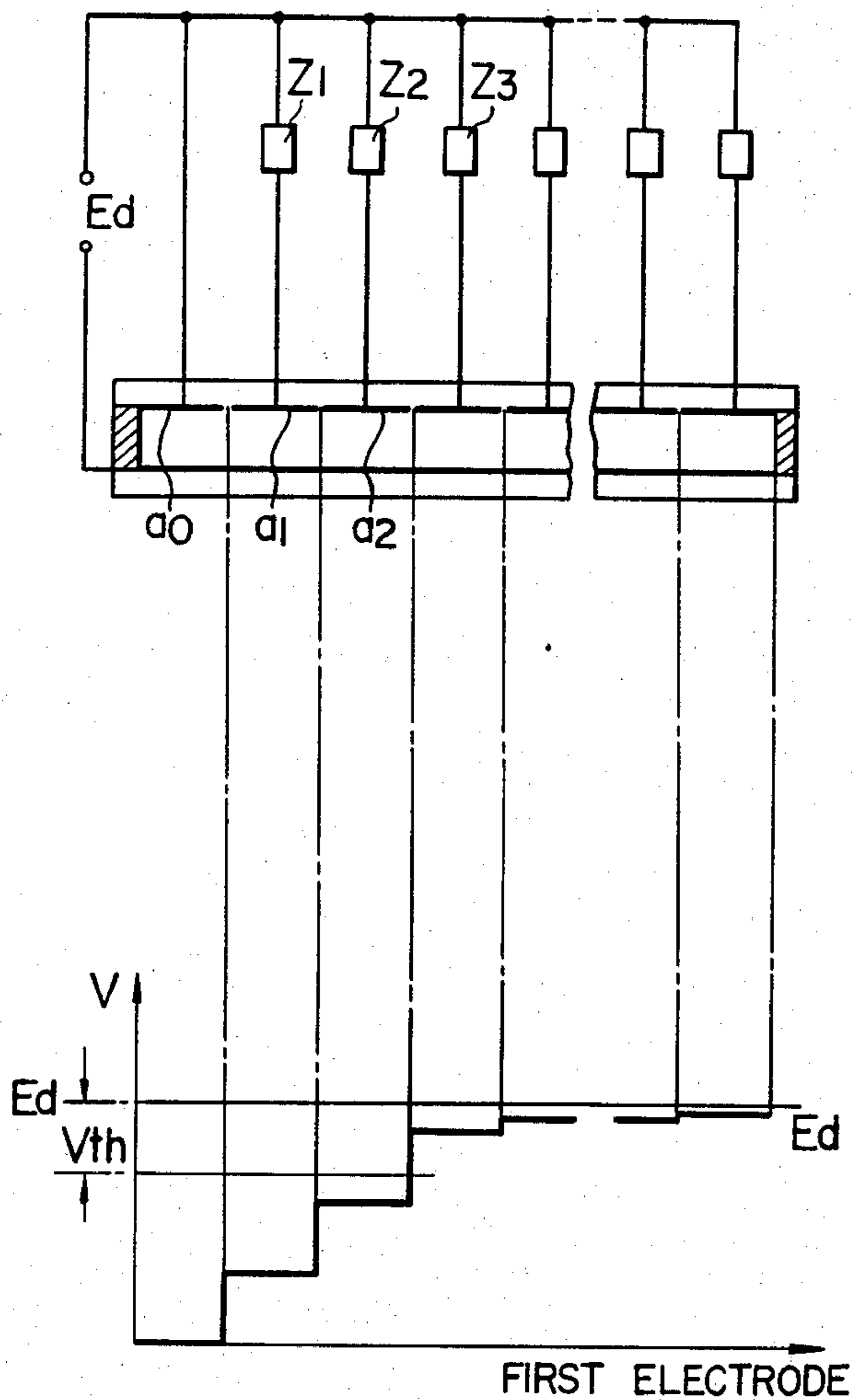


FIG. 17

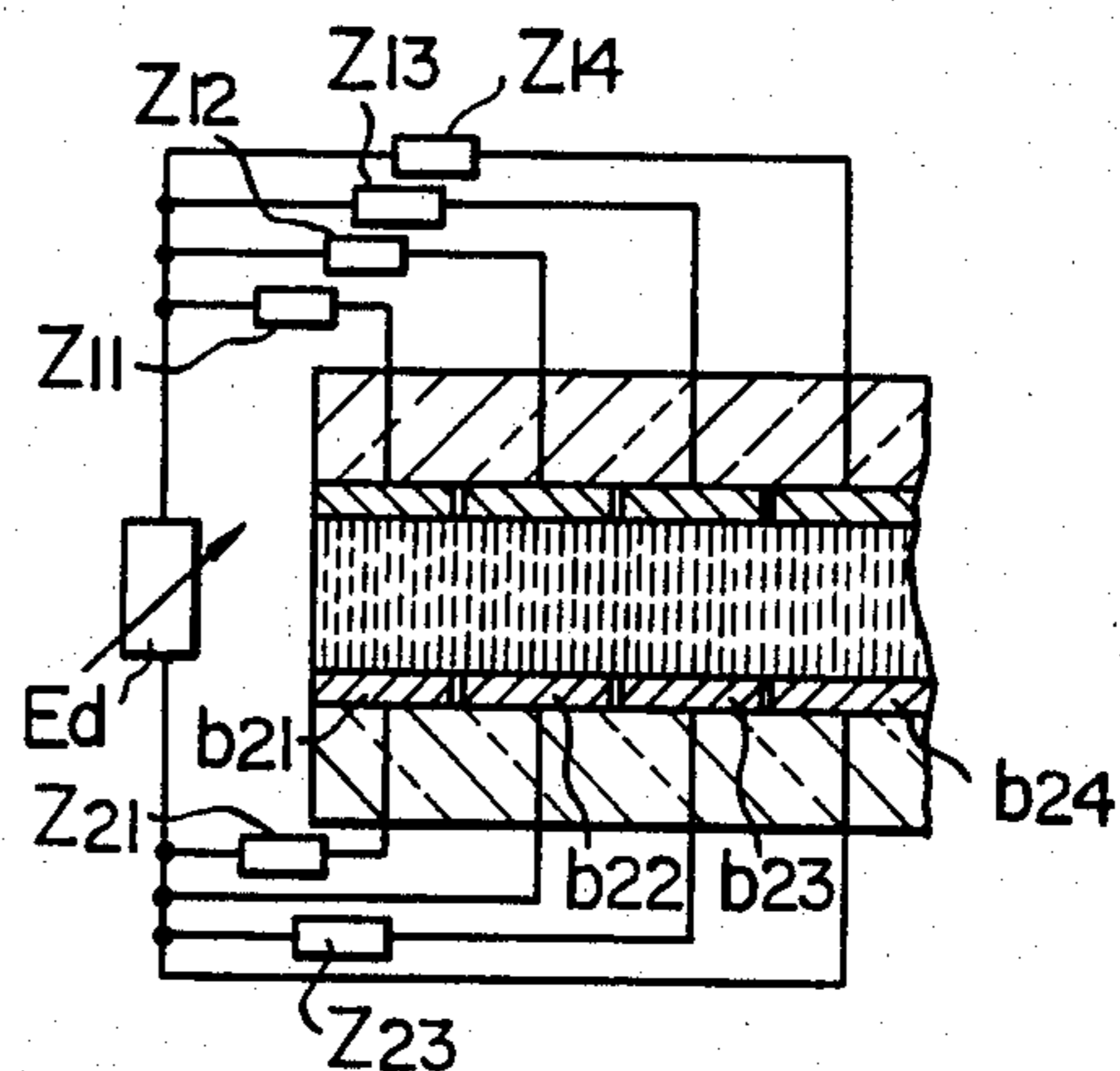


FIG. 18

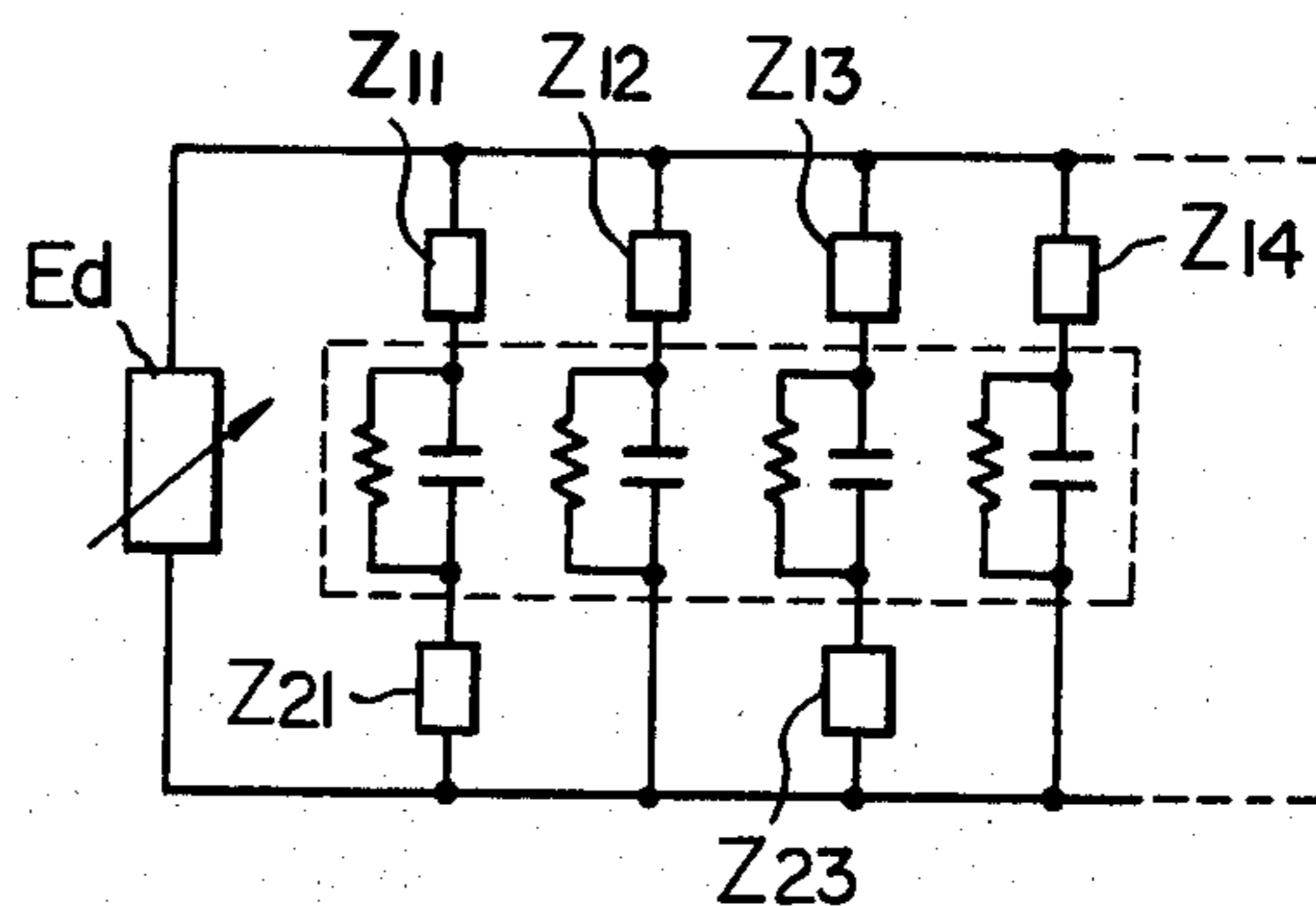


FIG. 19

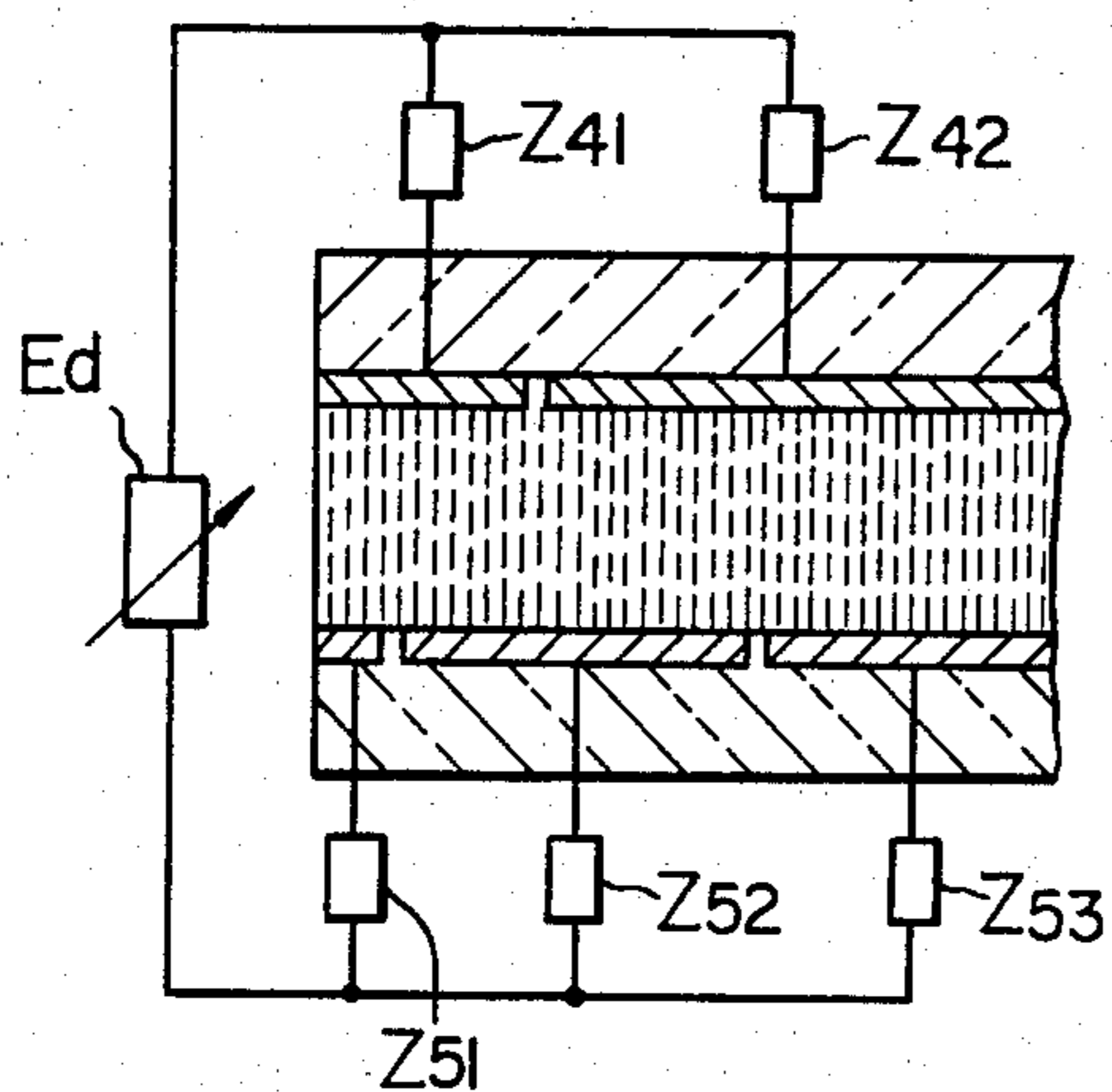


FIG. 20

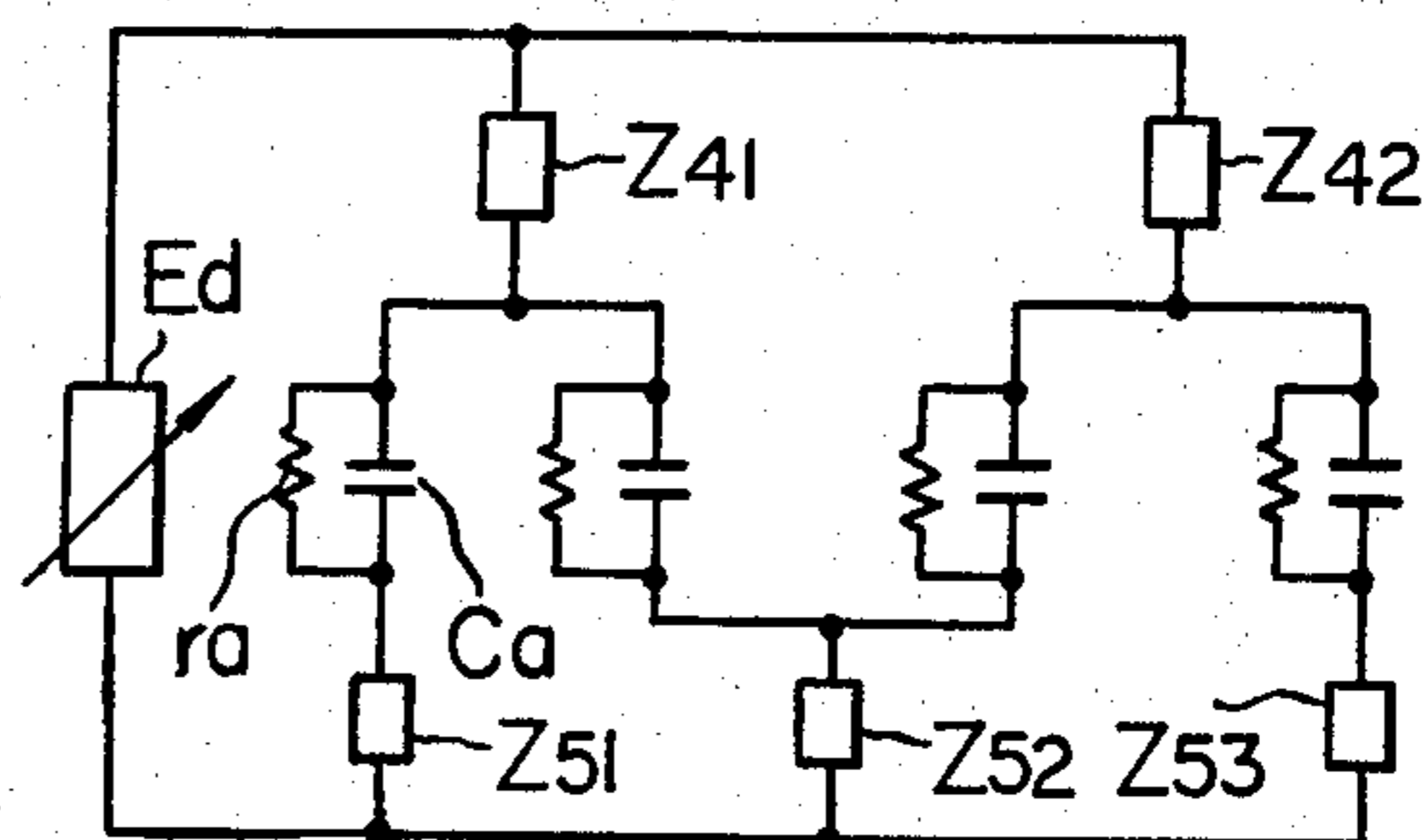


FIG. 21

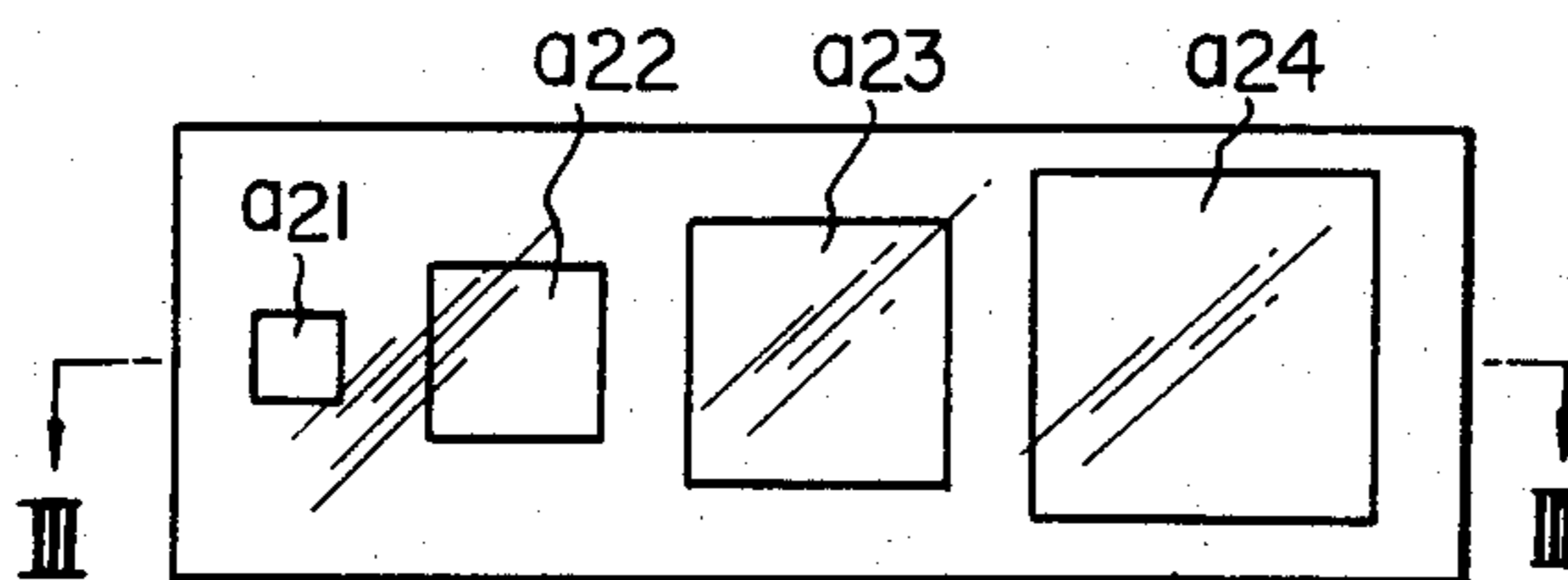


FIG. 22

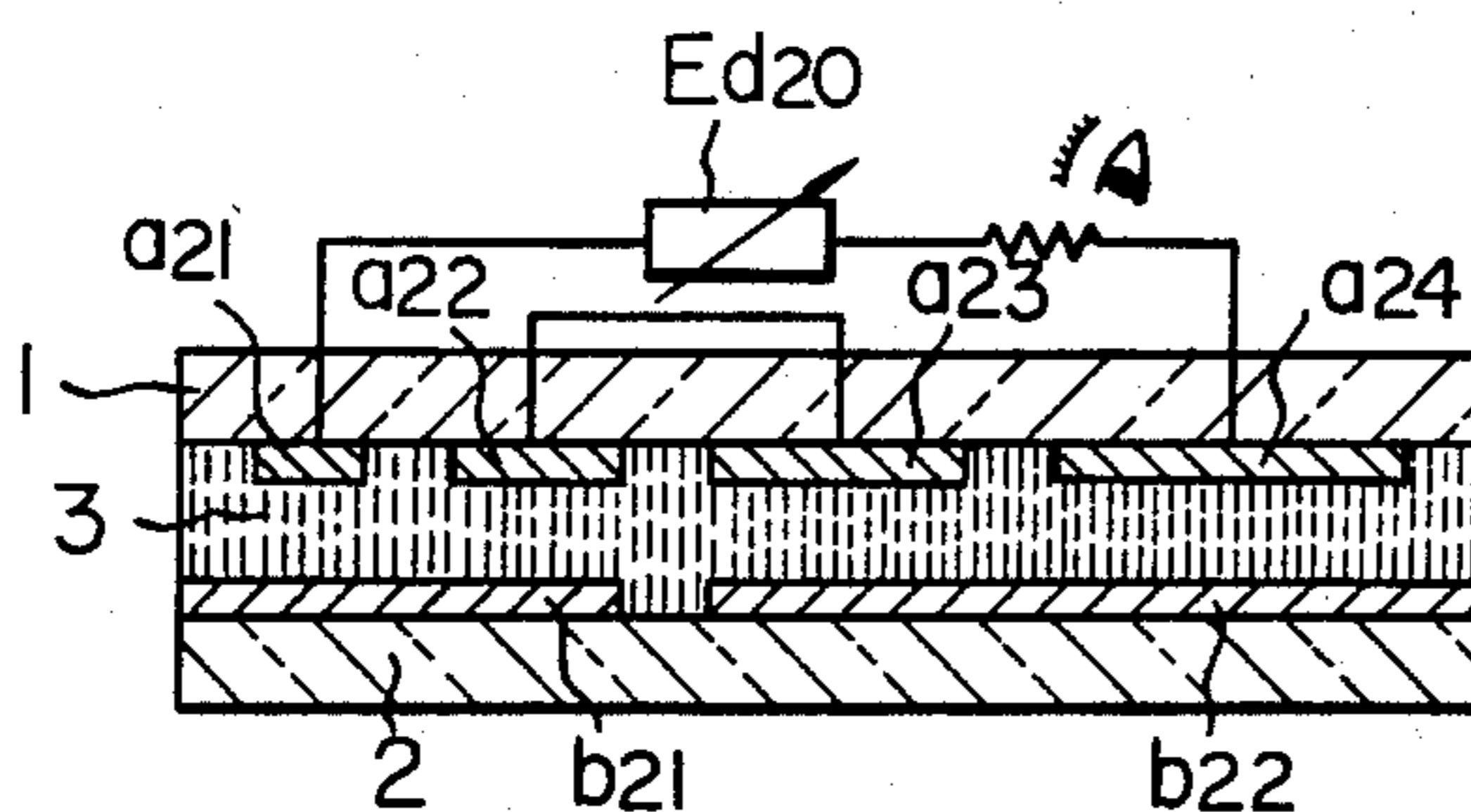


FIG. 24

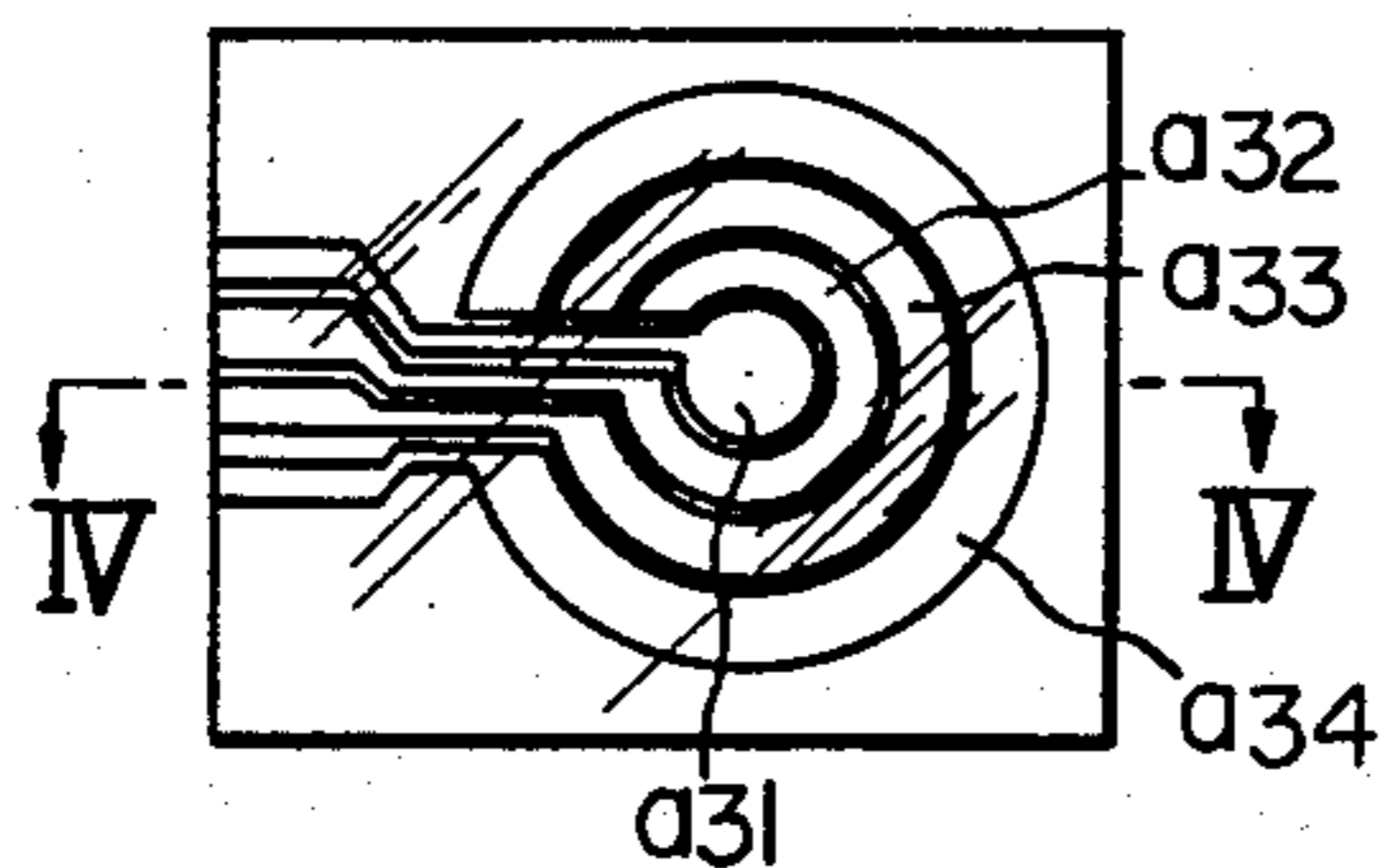


FIG. 26

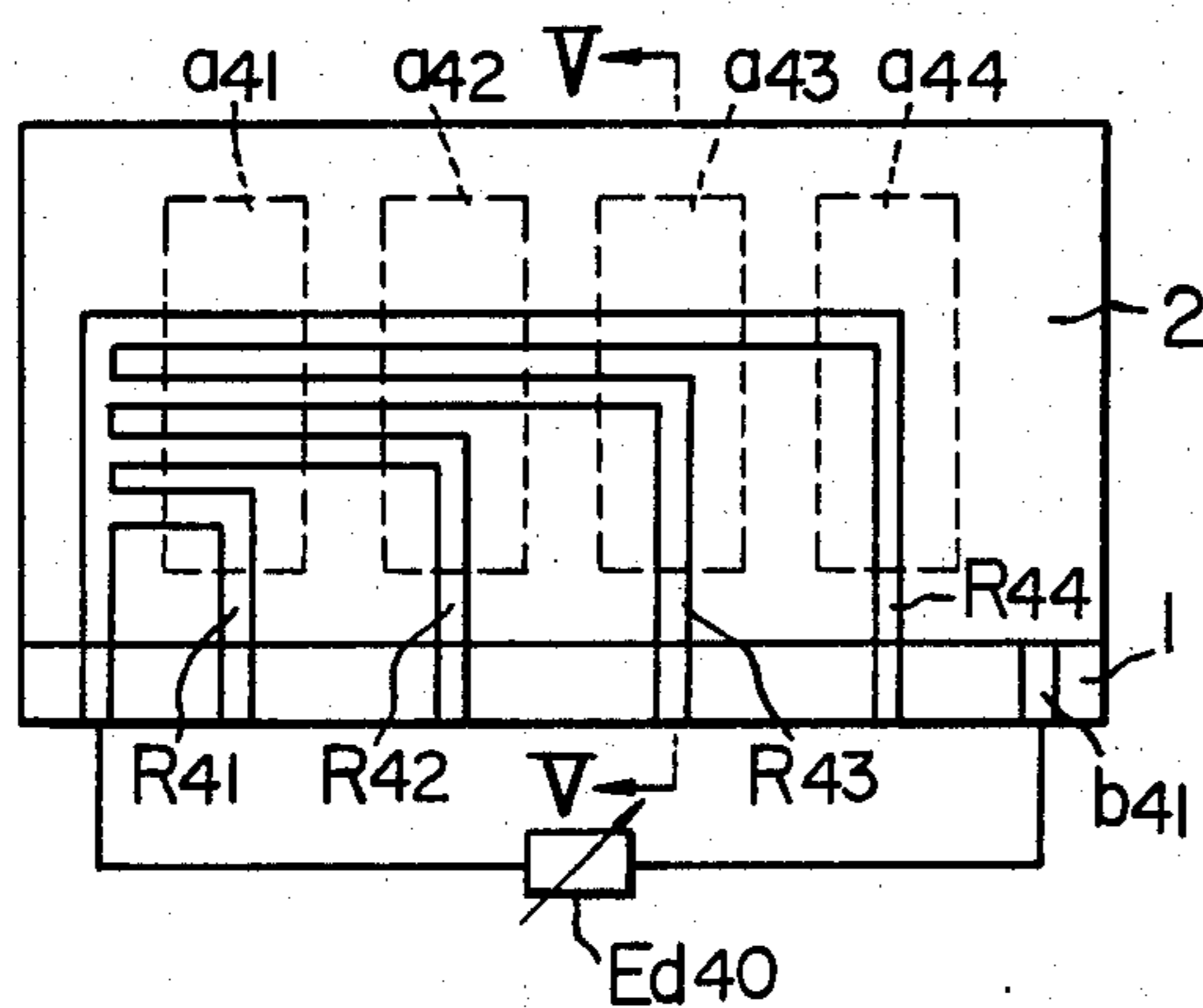


FIG. 23

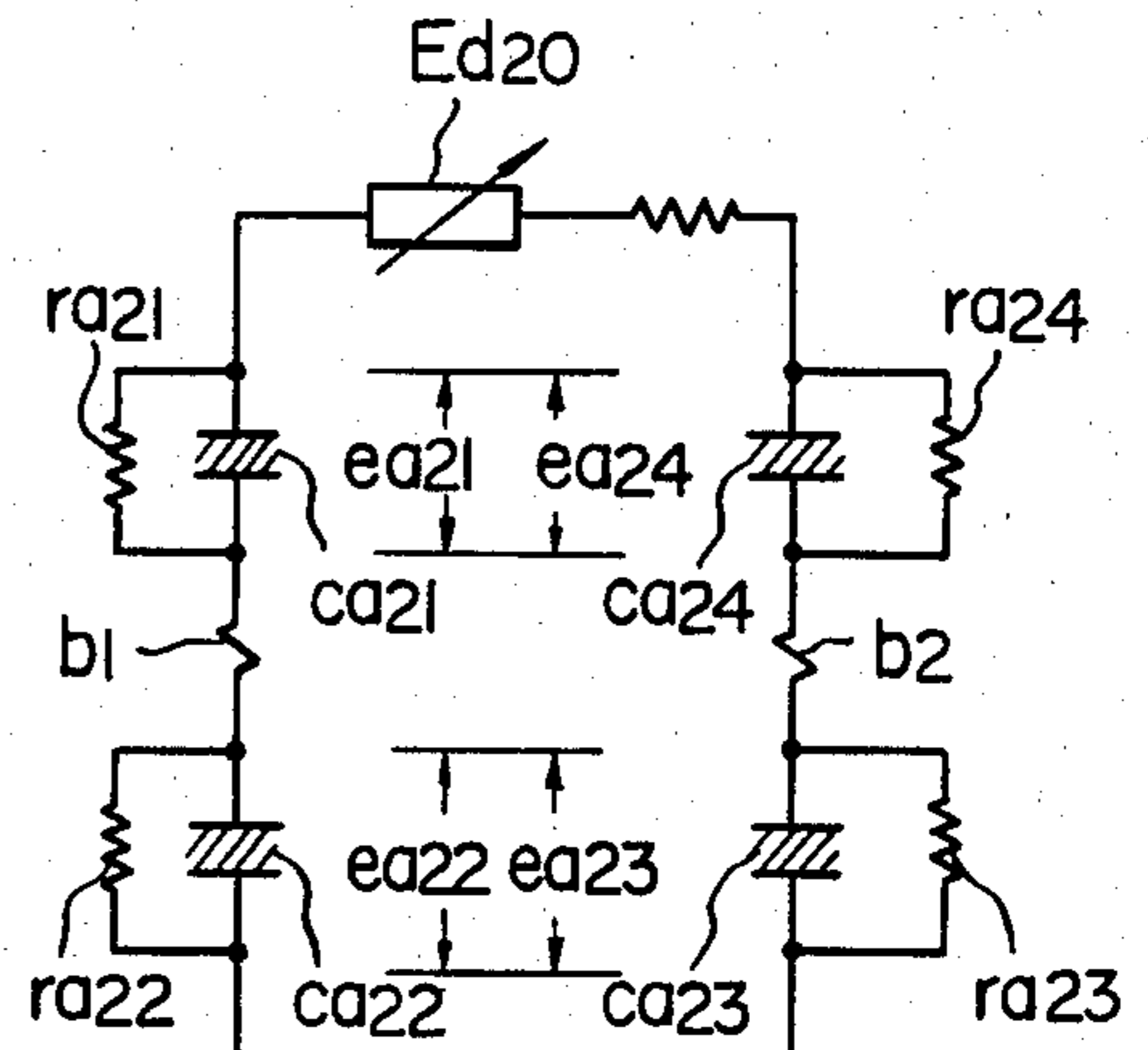


FIG. 25

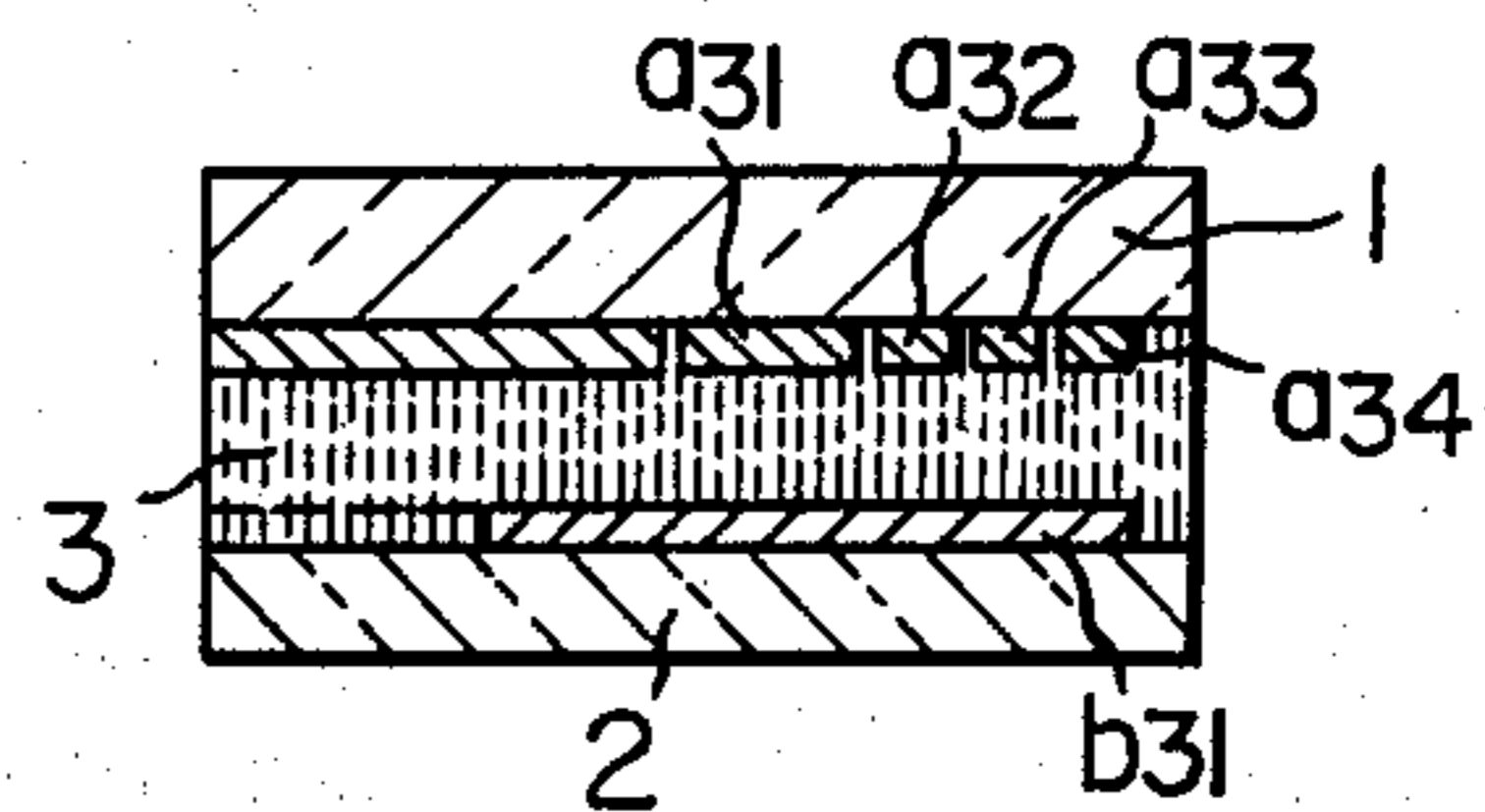


FIG. 27

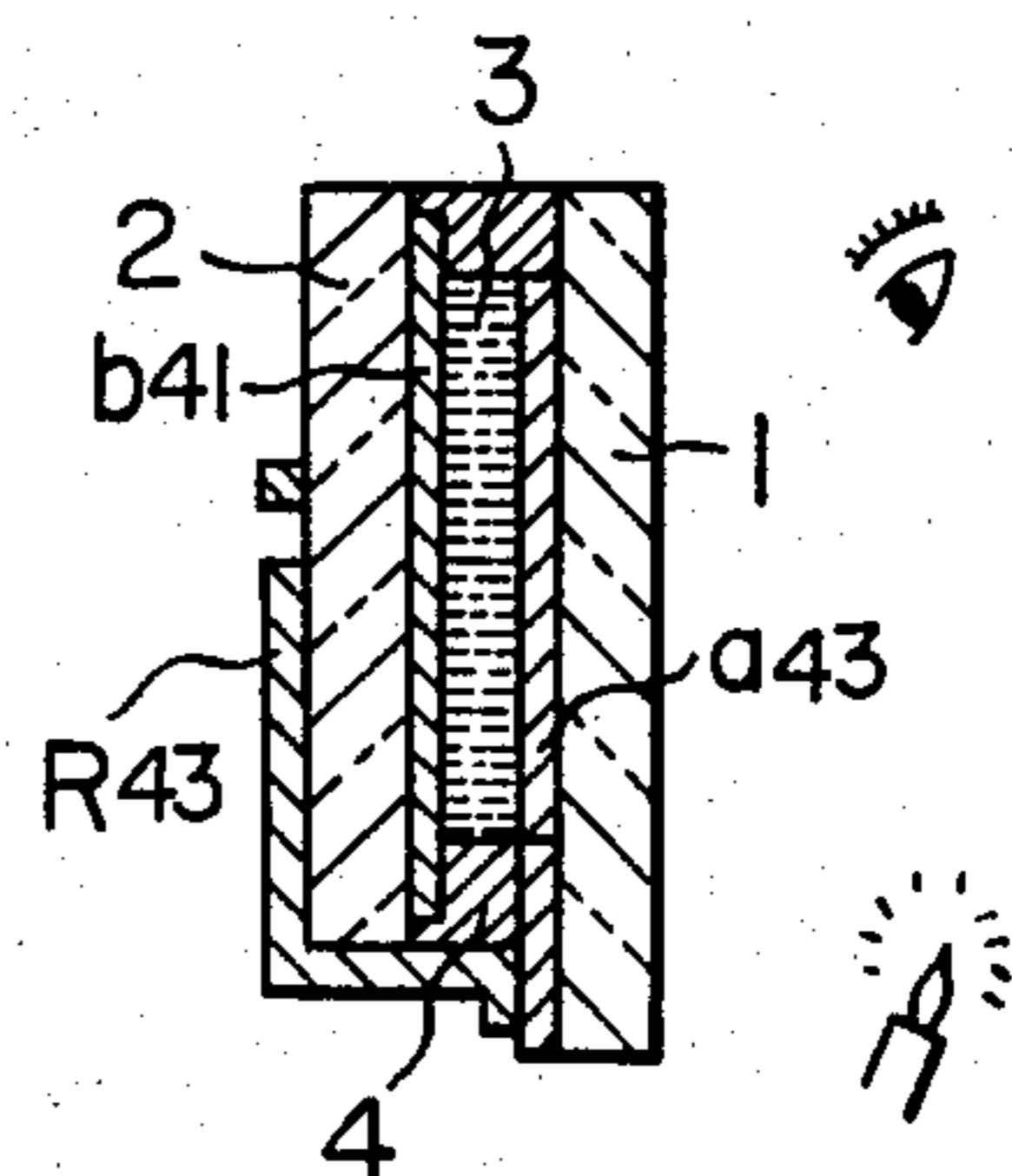


FIG. 28

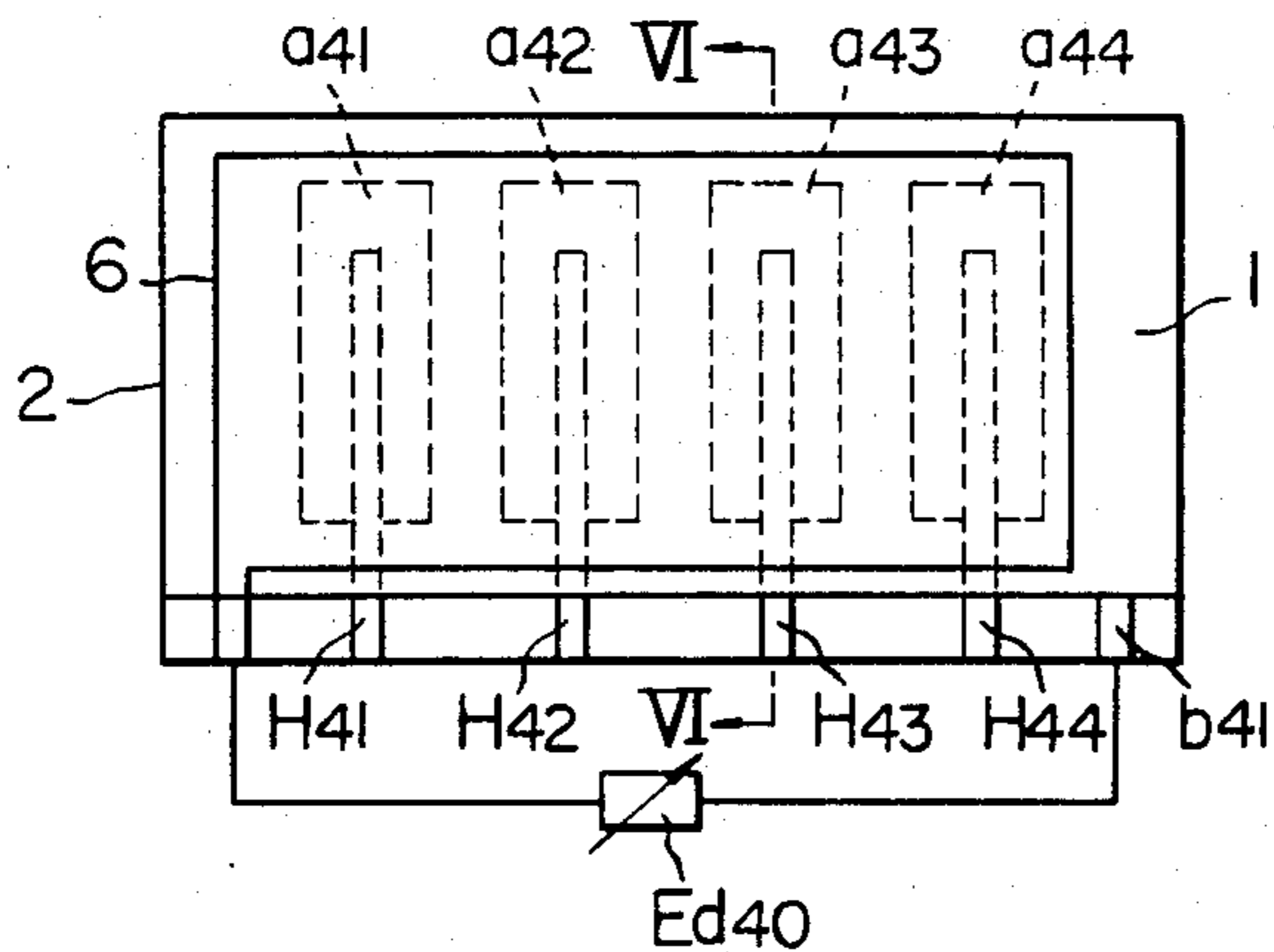


FIG. 29

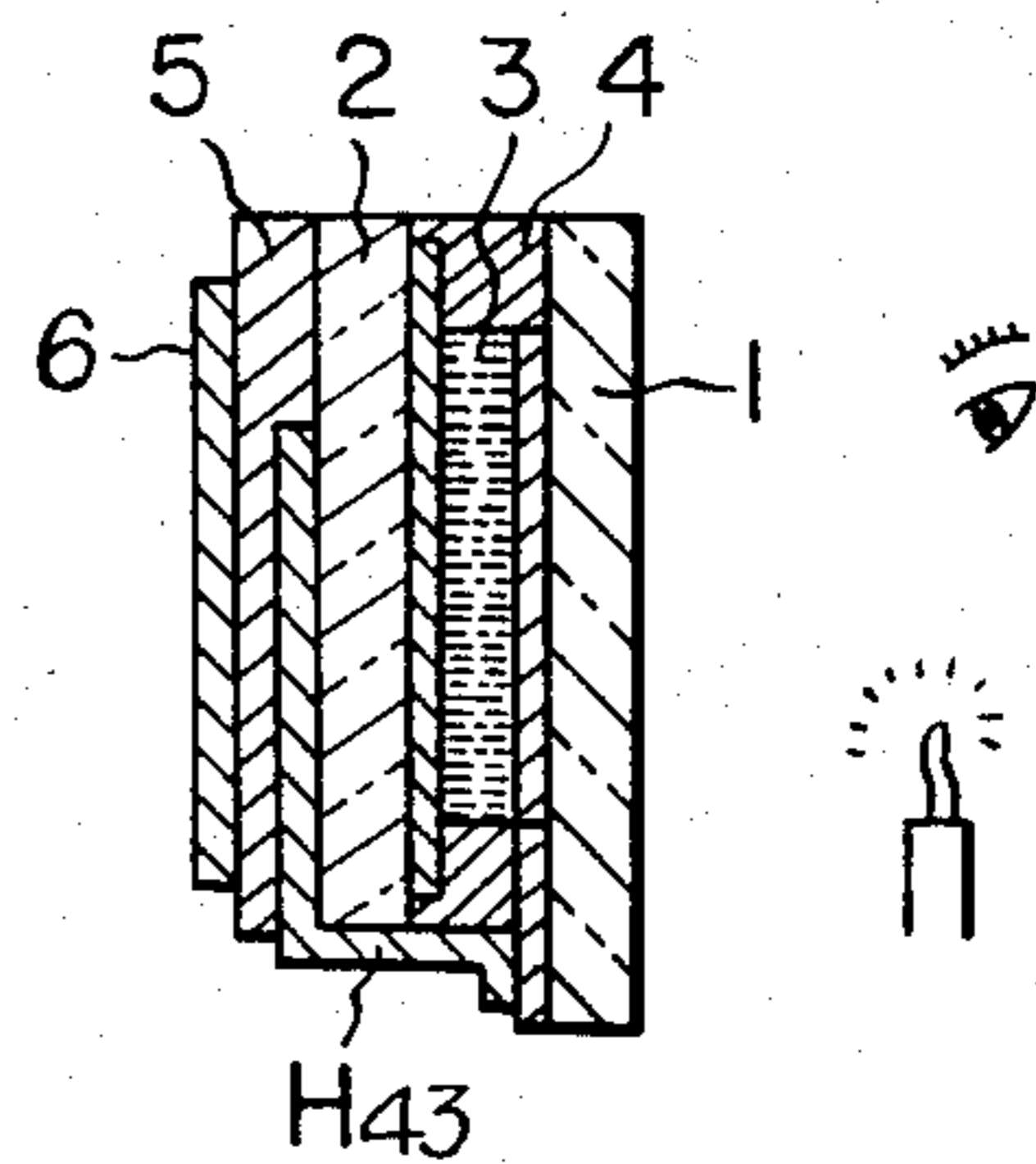


FIG. 30

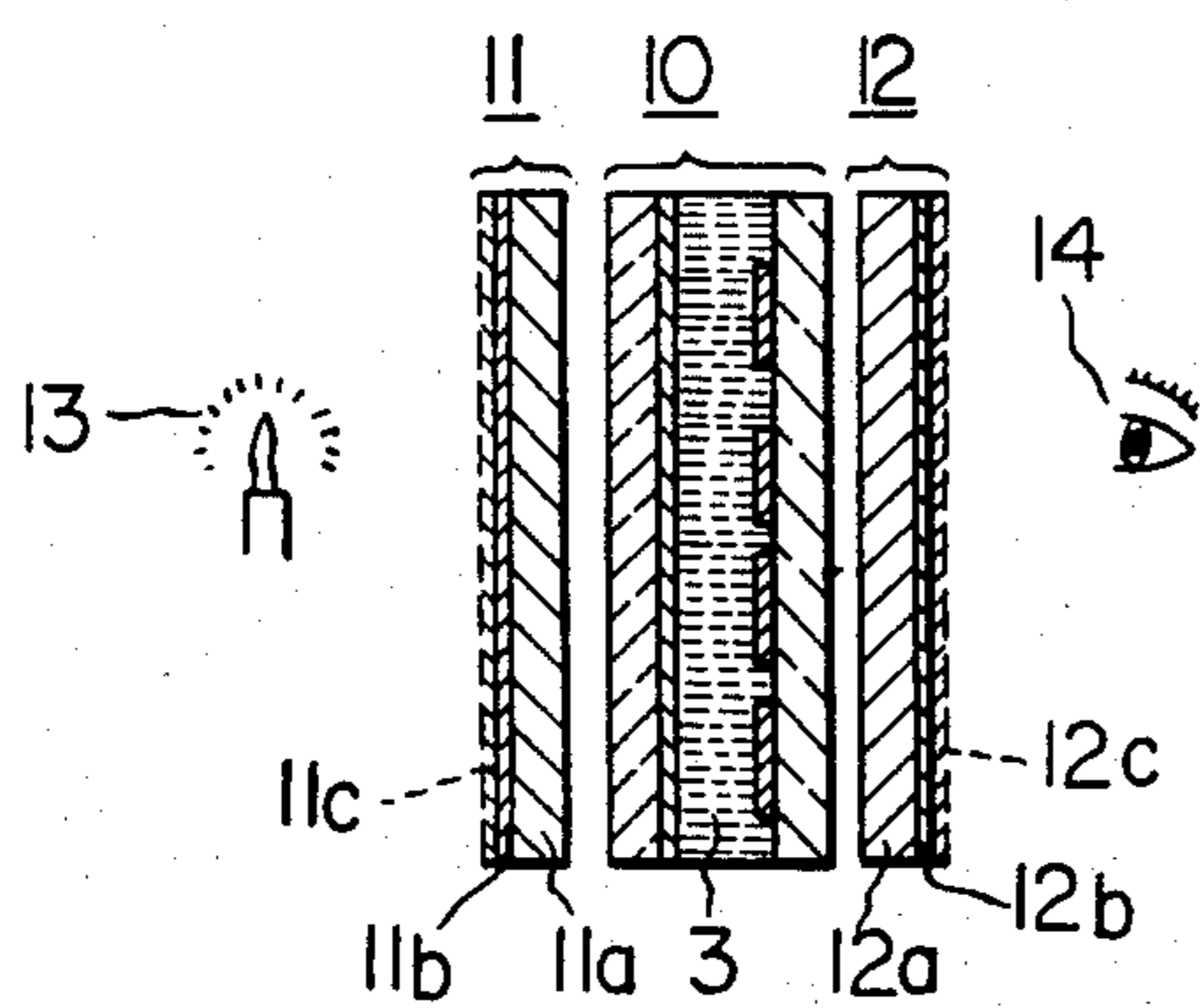


FIG. 31

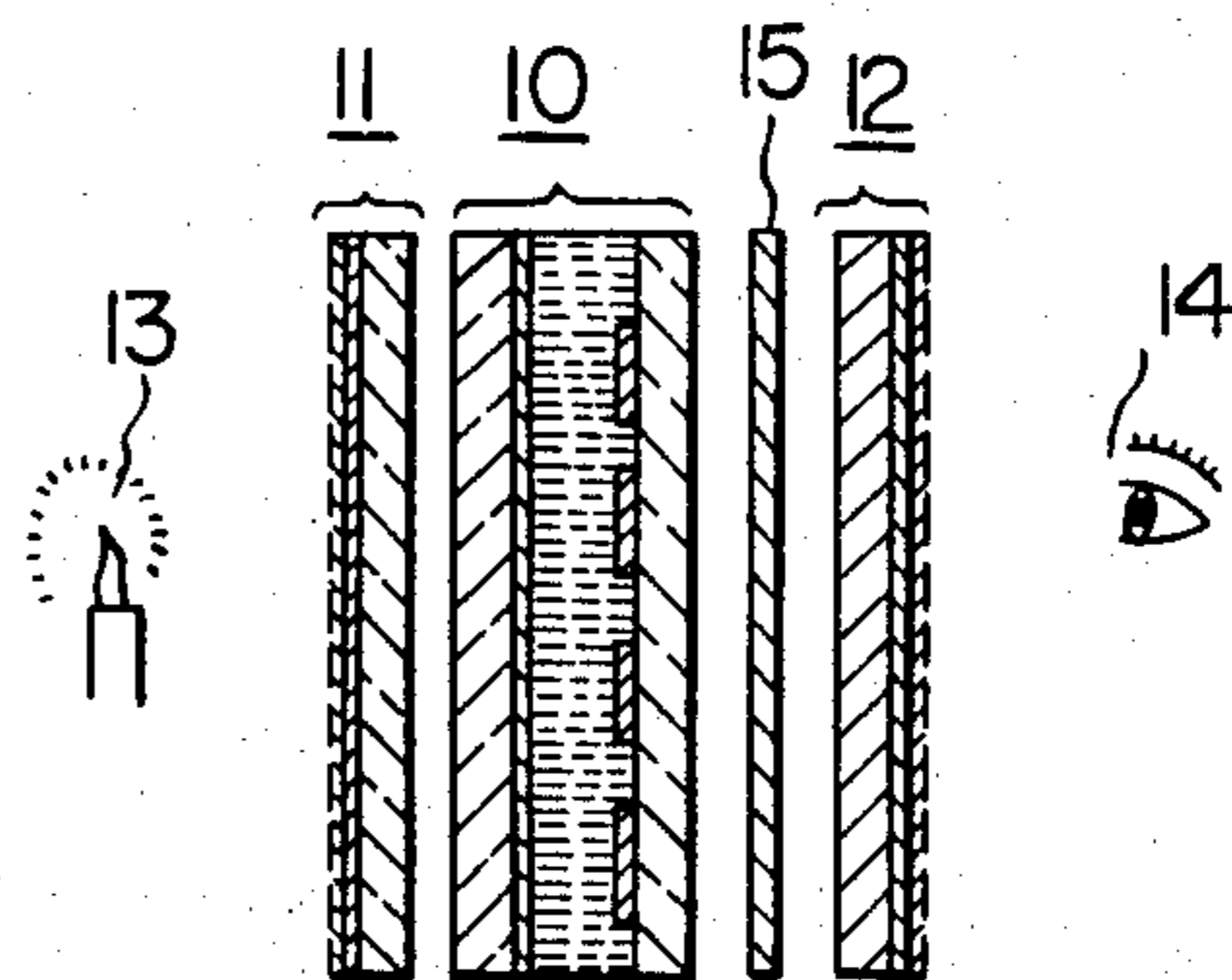


FIG. 32

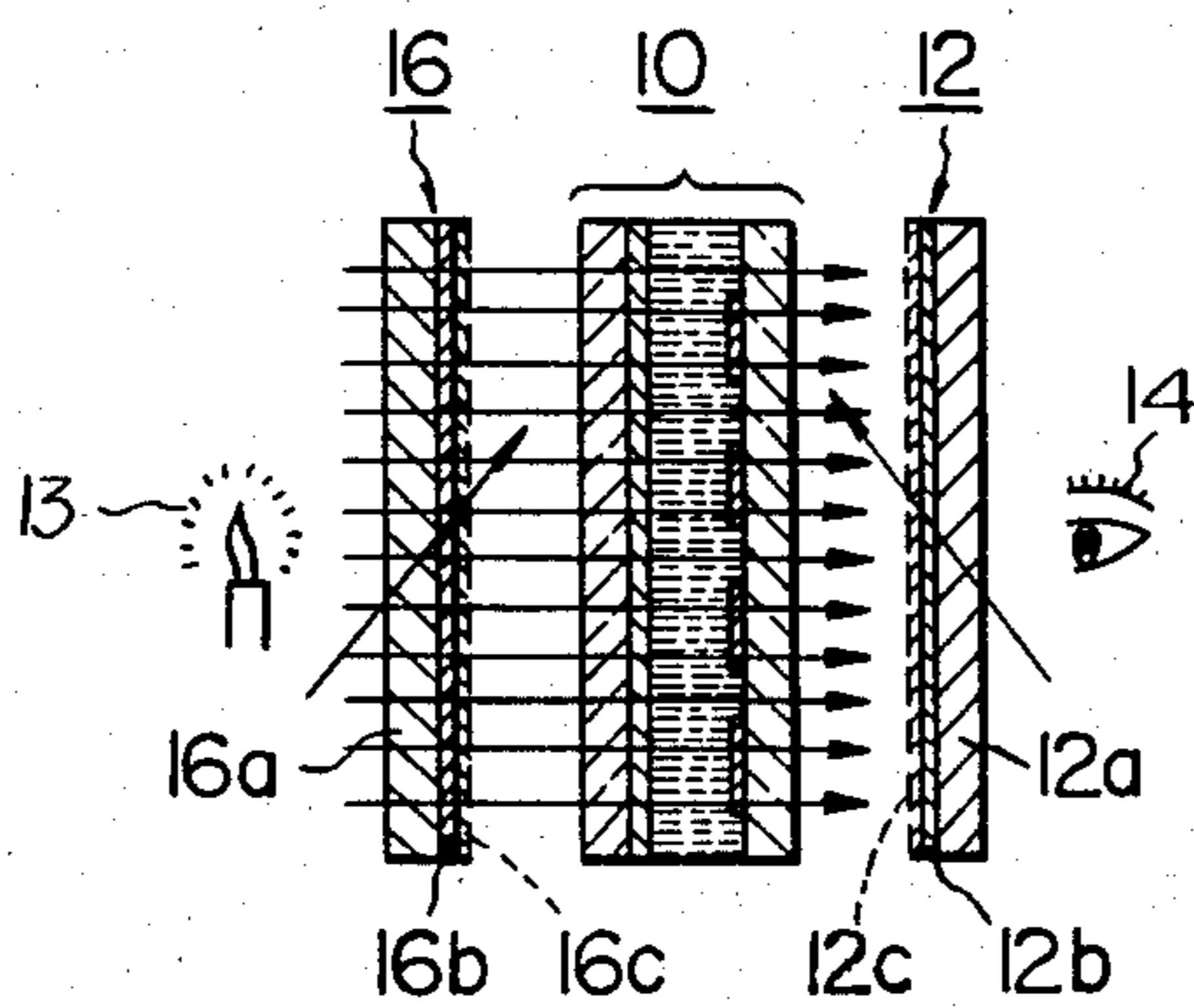


FIG. 33

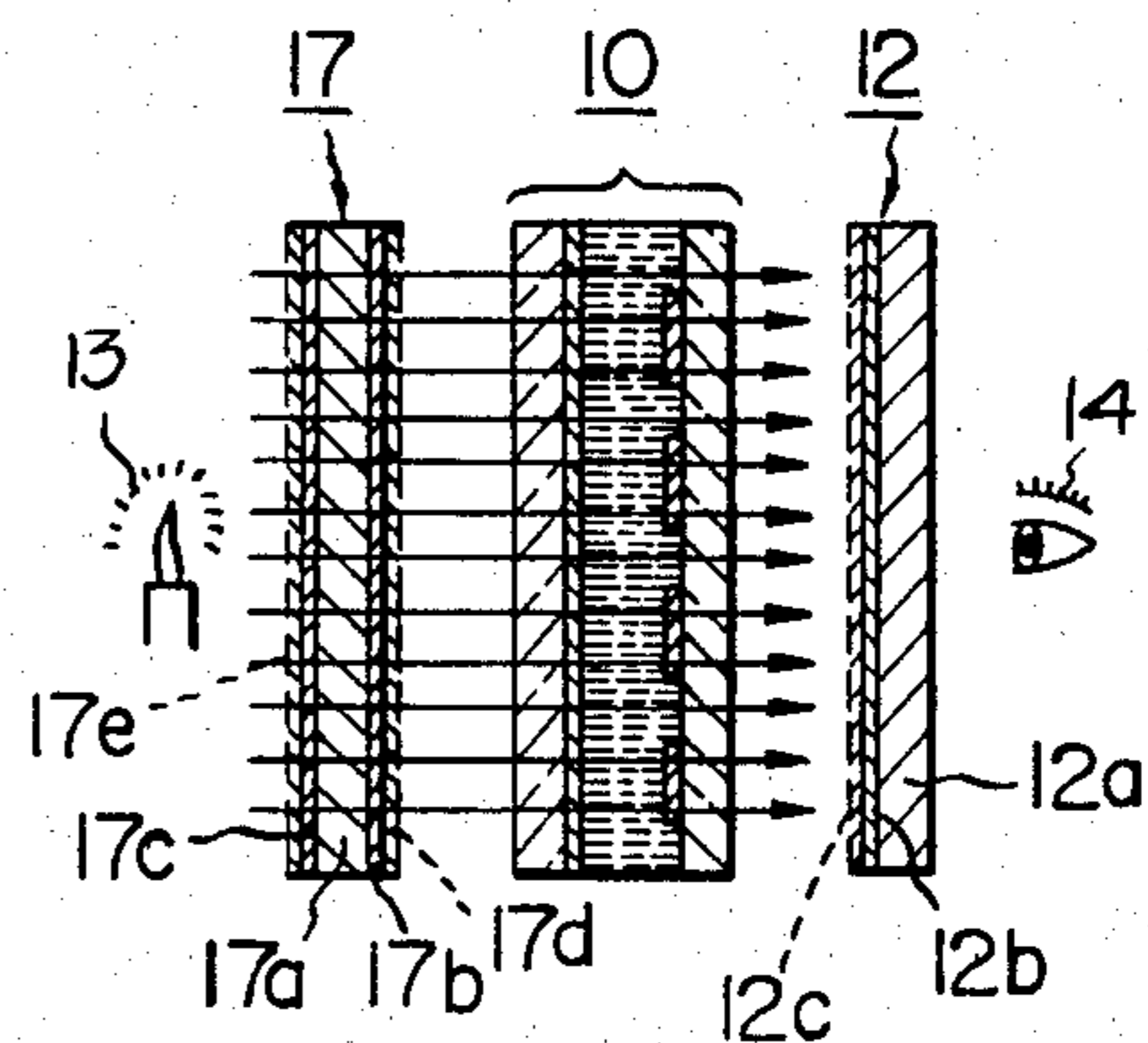


FIG. 34

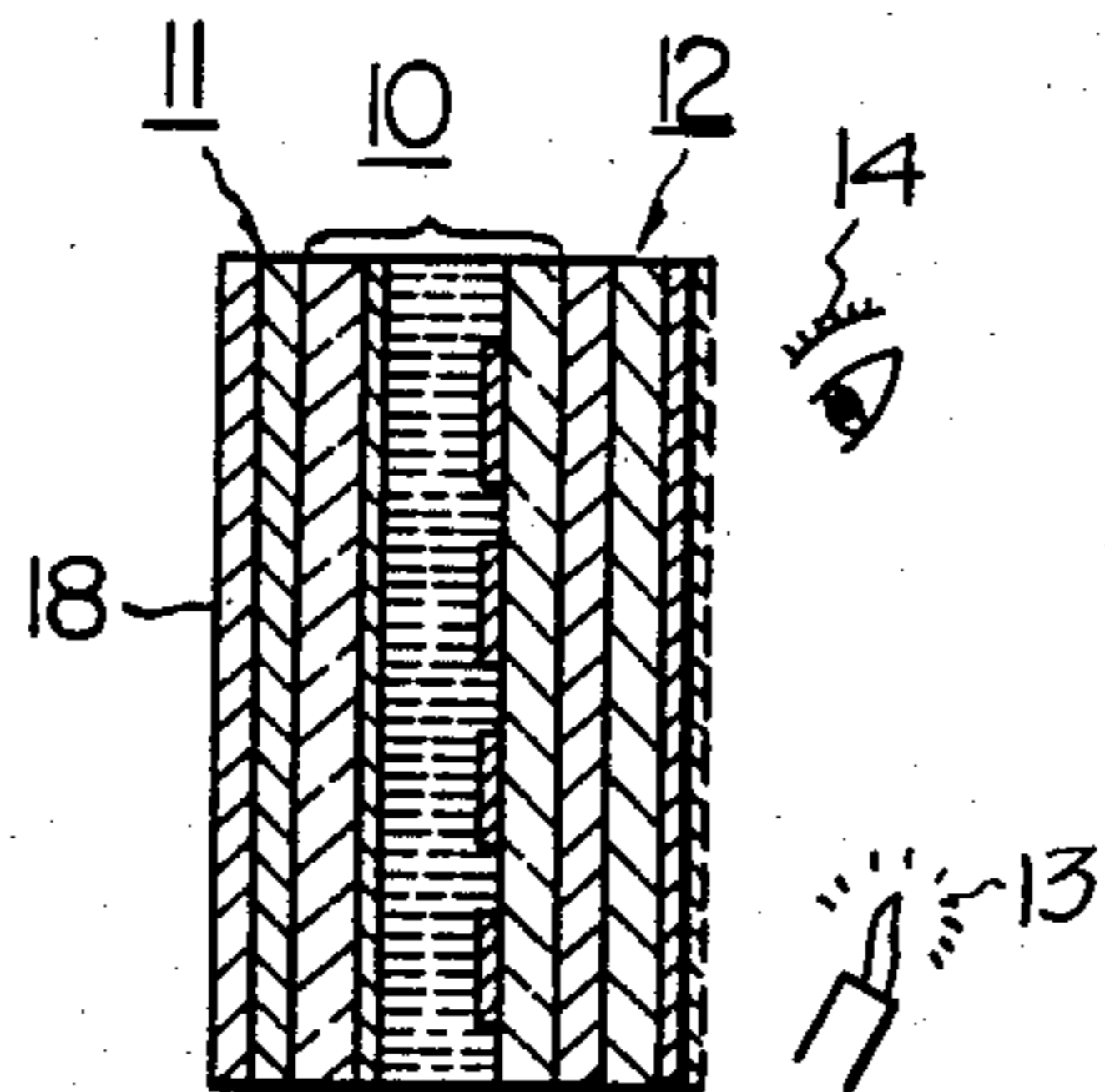


FIG. 35

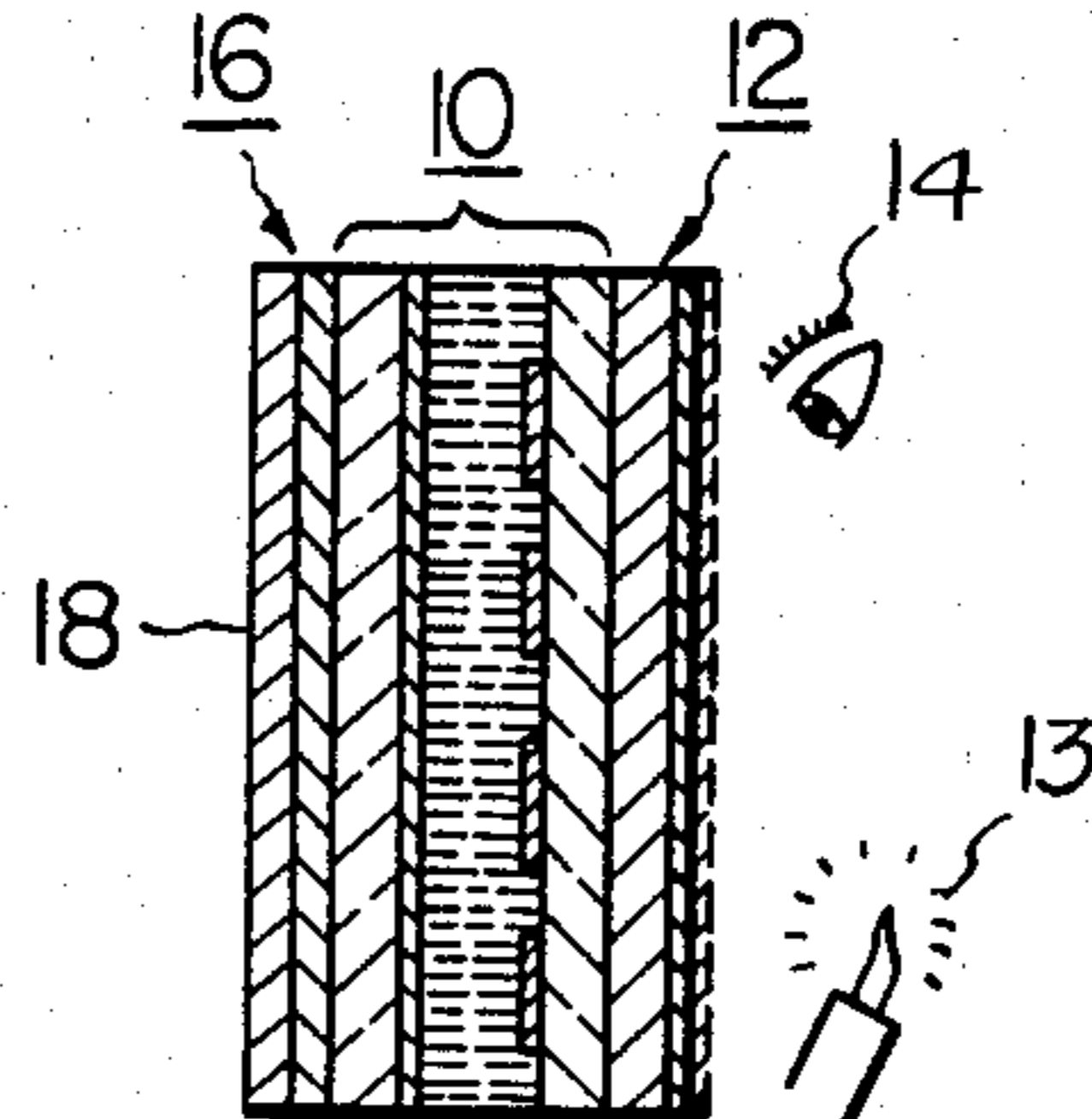


FIG. 36

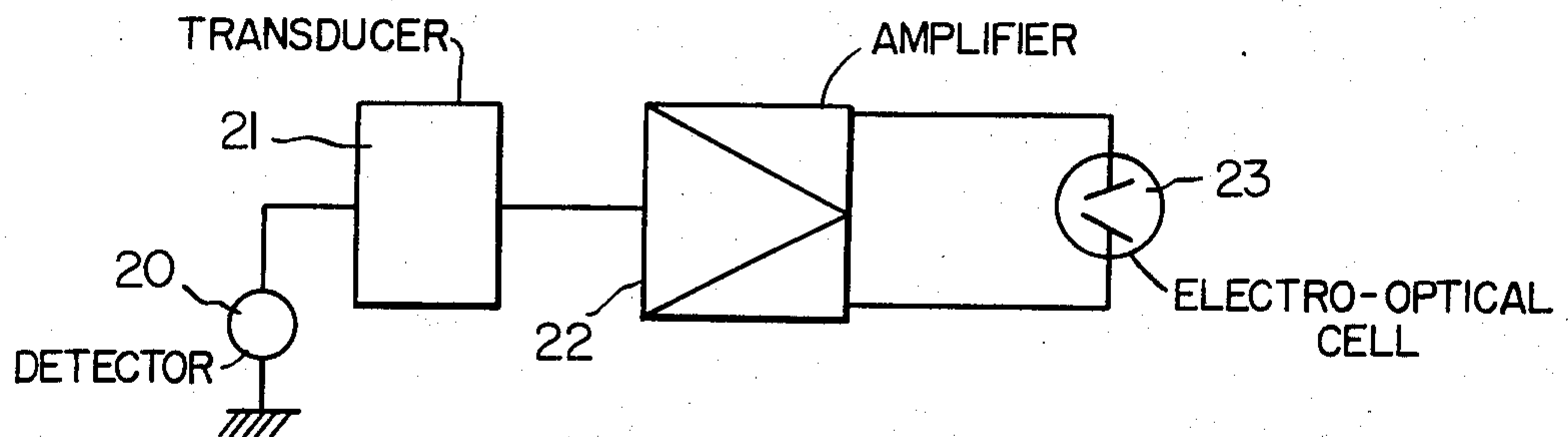


FIG. 37

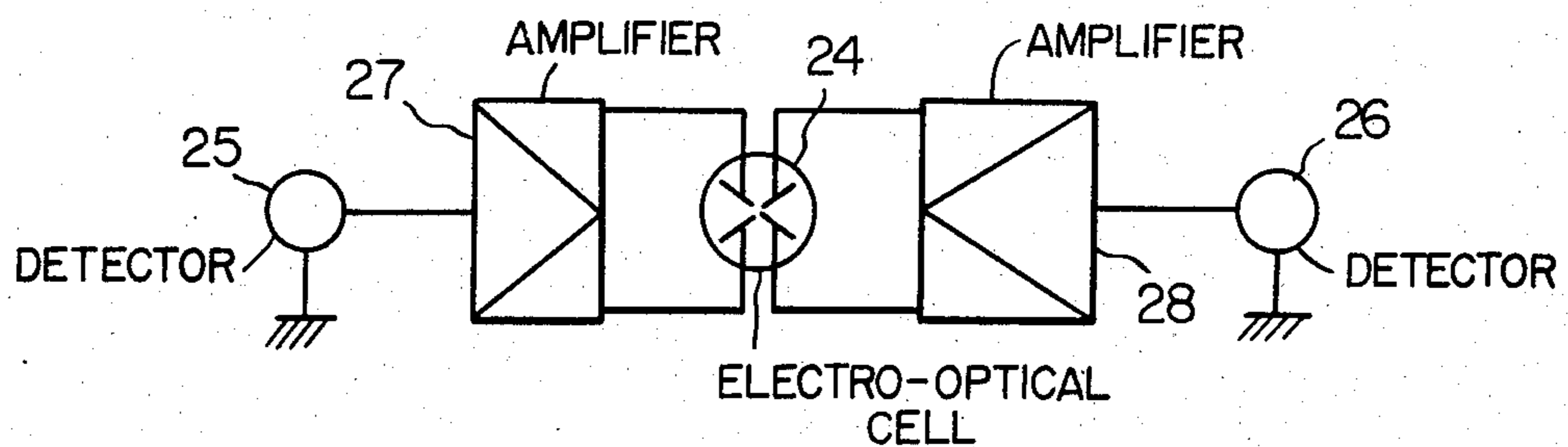


FIG. 38

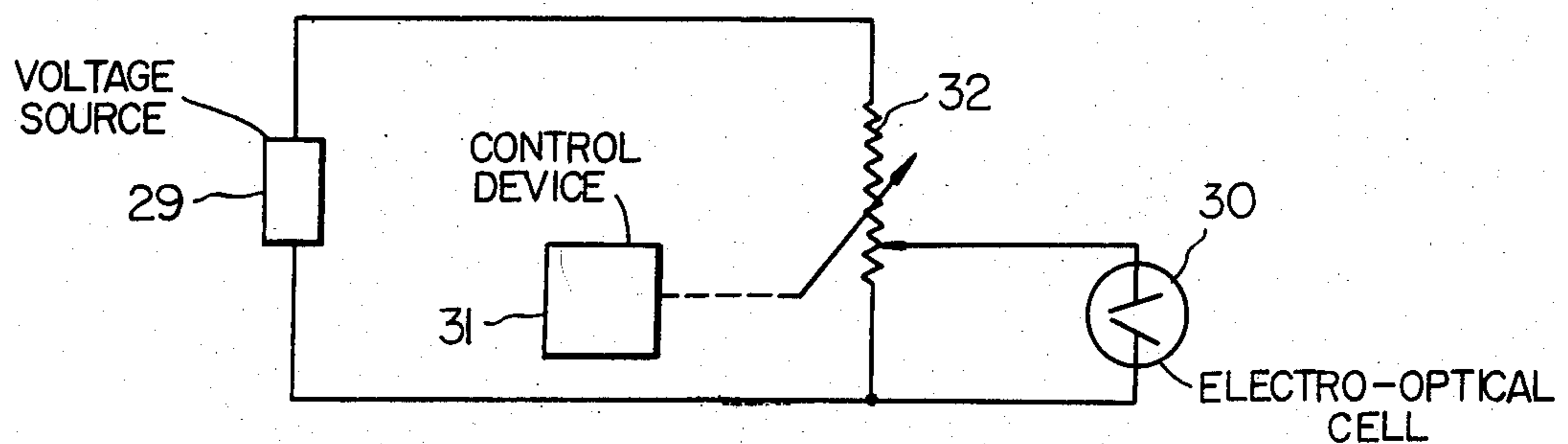


FIG. 39

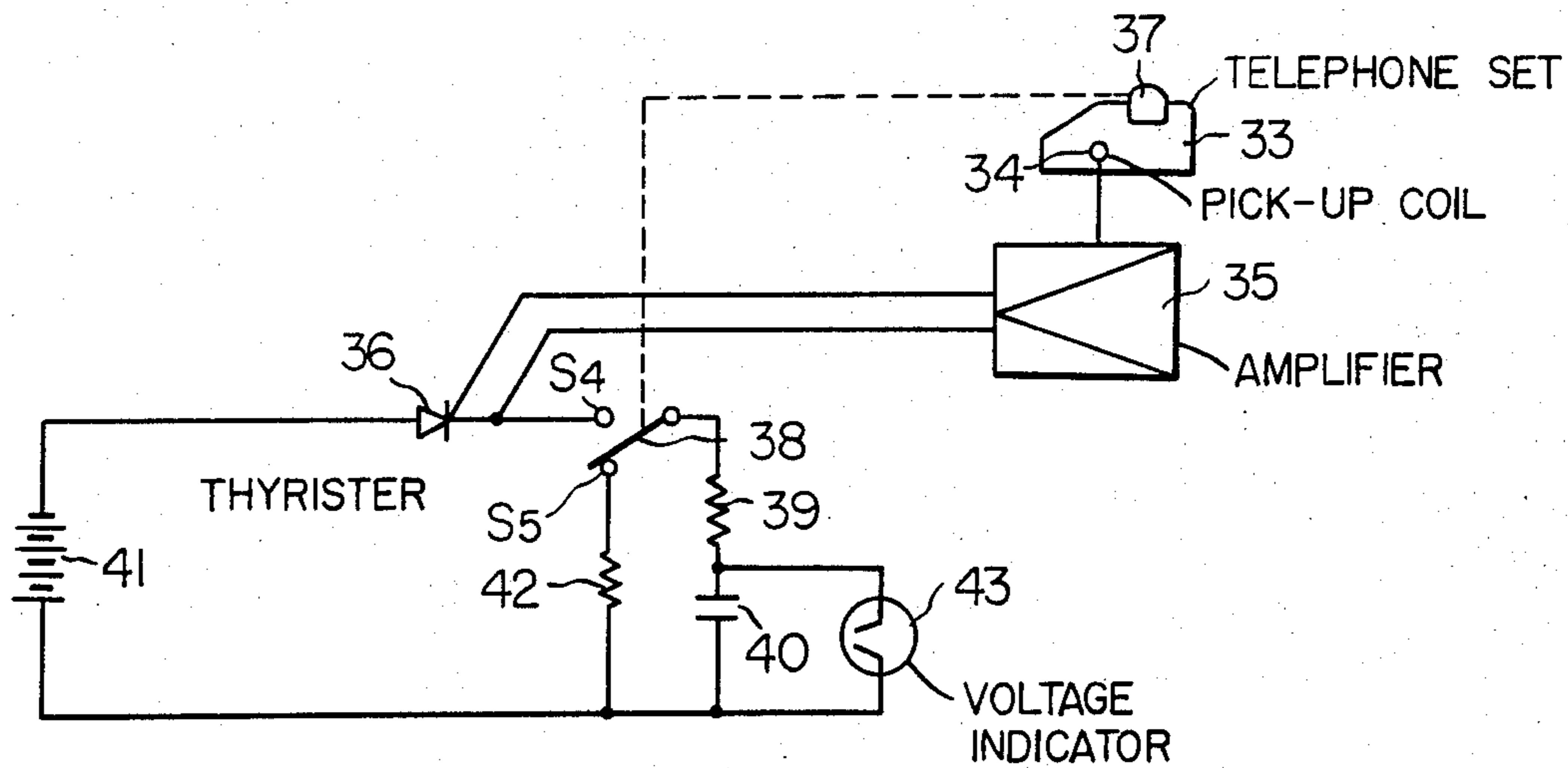


FIG. 40

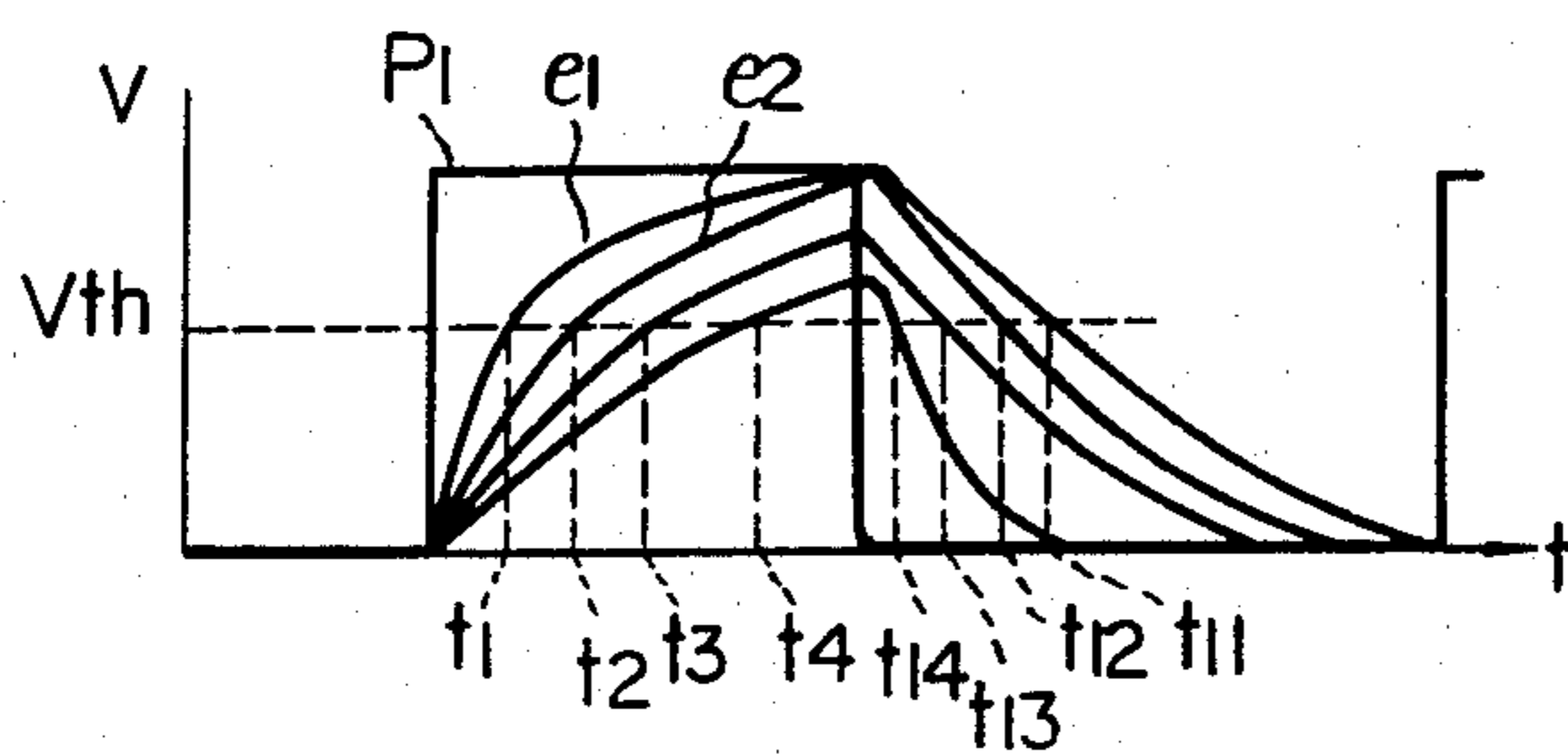


FIG. 41

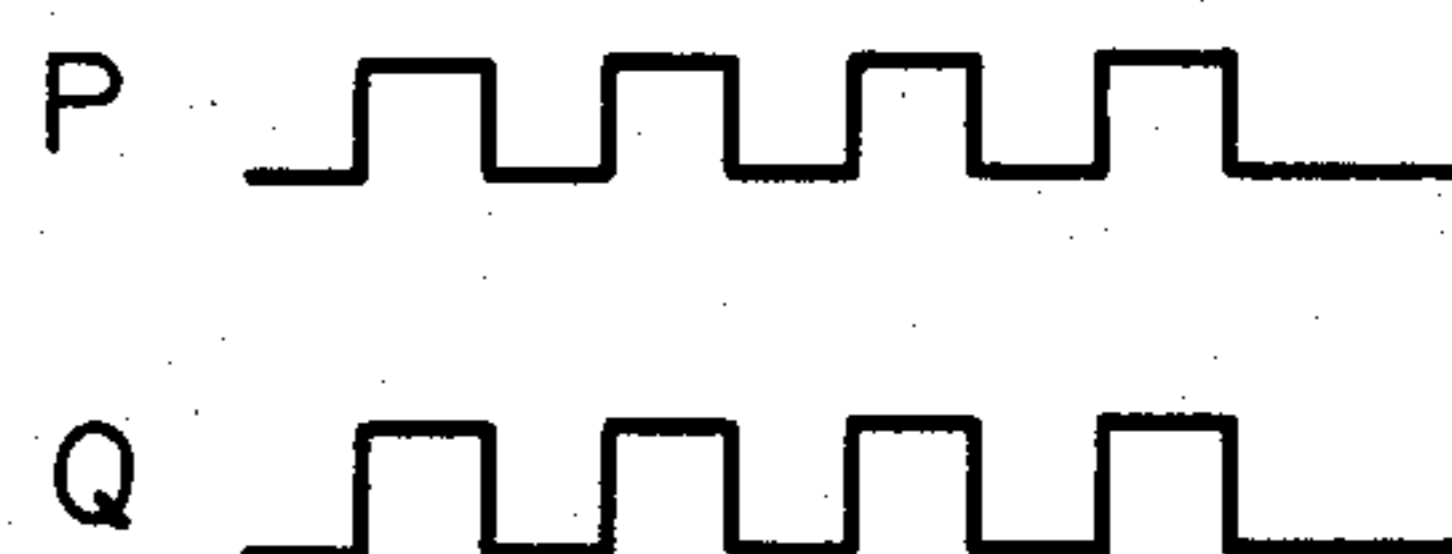


FIG. 42

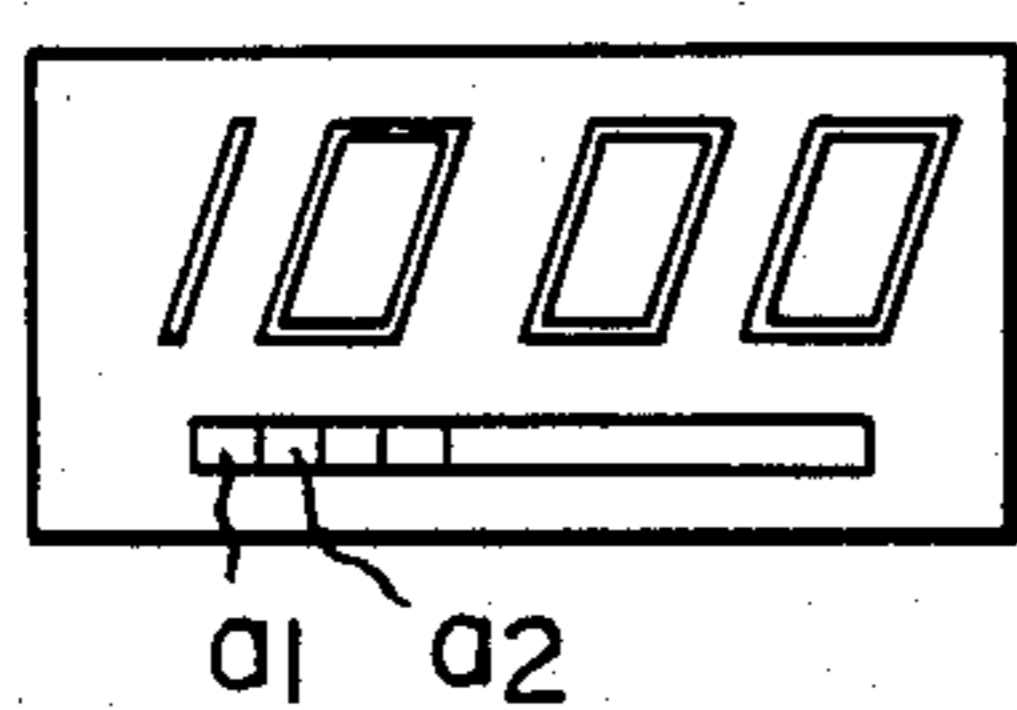


FIG. 43

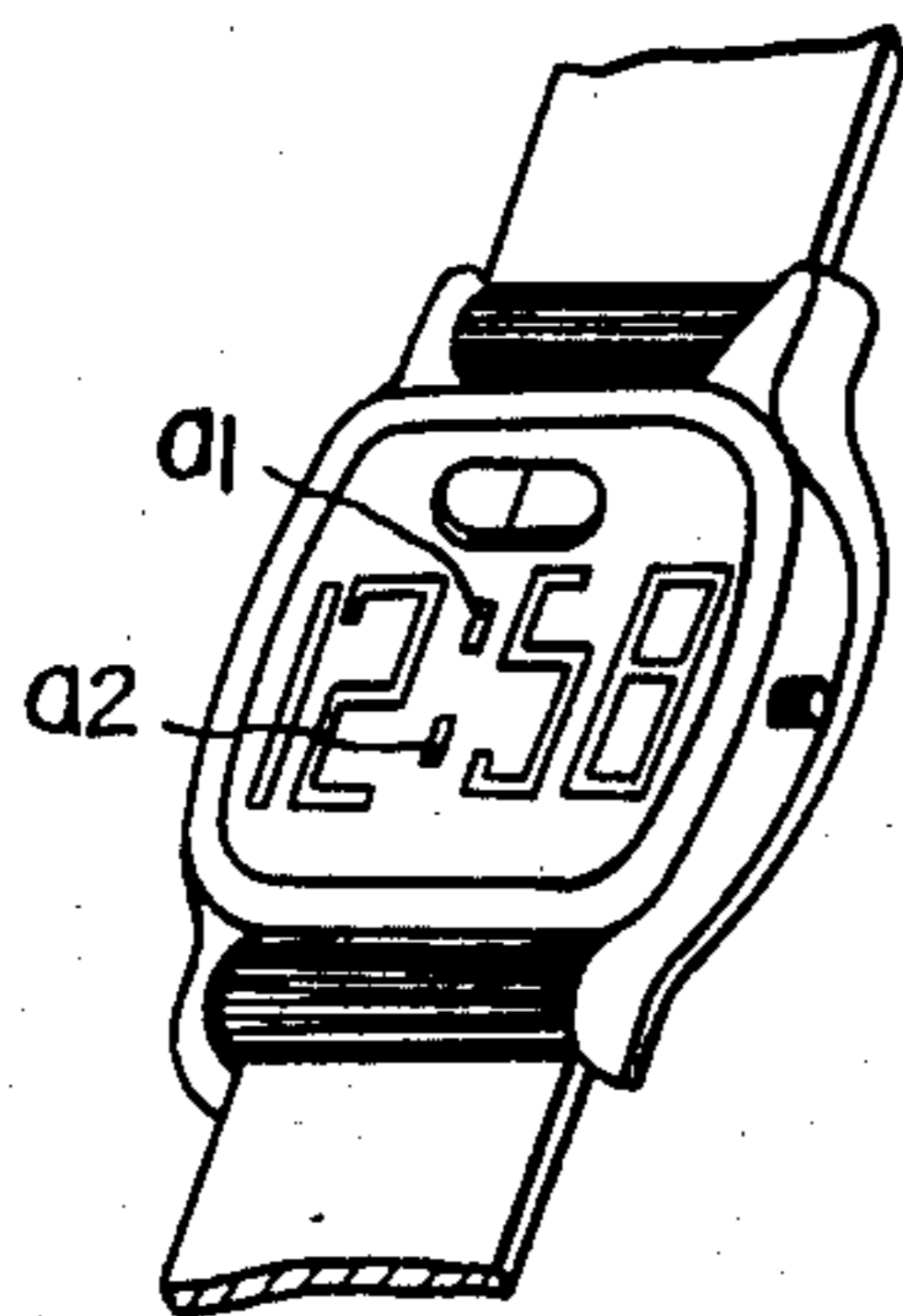
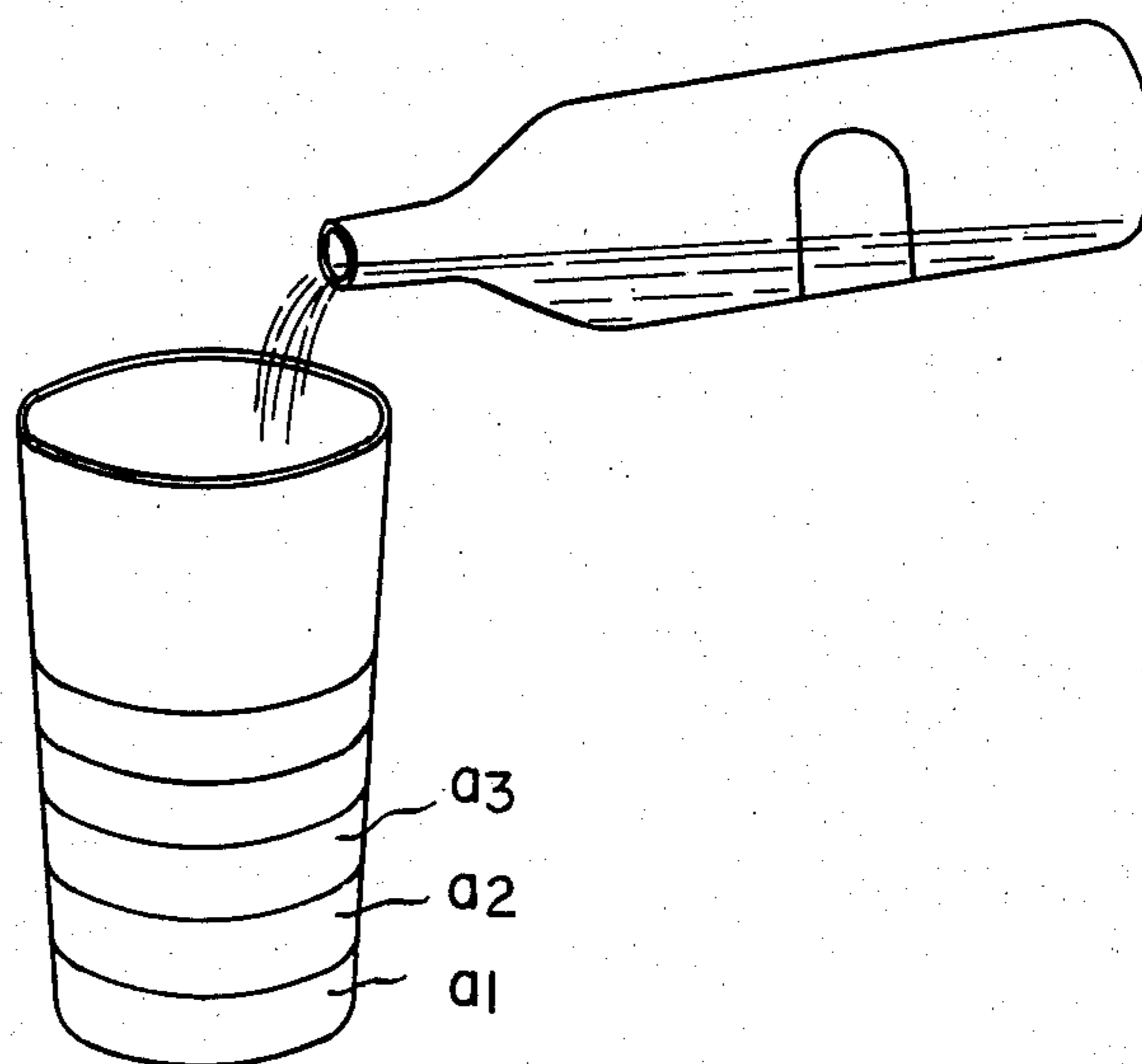


FIG. 44



ELECTRO-OPTIC DEVICE

BACKGROUND OF THE INVENTION

This invention relates to an electro-optic device used for various display devices which display an image having a monochrome and/or colored tone partially light and shade or to an electro-optic device useful for optical valves, shades or screens.

Various electro-optic devices which present or show a peculiar electro-optical phenomenon in a relatively low electric field are well known in the art. Such electro-optic devices can be divided into two groups; one group including so-called crystalline liquids, that is, some of the organic substances presenting mesophase indicating that they are states of material intermediate between the liquid and crystalline states or mixtures of these organic substances and the other group including so-called colloidal liquids which are obtained by dispersing a non-organic crystal such as tungsten oxide and vanadium oxide or an anisotropic crystal such as herapathite in a solvent, a typical one of which is the colloidal liquid on the market named VARAD (made by MARKS POLARIZED CO.).

When an electric field is applied to such an electro-optical material, for instance a crystalline liquid; in one case, it changed its state, that is, it changes from a state of presenting an optical isotropy to a state of presenting an optical anisotropy, and in another case, it changes from the state of presenting an optical isotropy to a state of a molecular turbulent flow thereby to uniformly scatter incident light. In addition, a certain type of crystalline liquid material selectively reflects only the light of a particular wave length upon application of an electric field thereto.

Such peculiar optical properties of crystalline liquid material are utilized in a conventional crystalline liquid display device known in the art. Such a conventional crystalline liquid display device is provided with a plurality of electrodes for optical image-creating, confronted each other, on both side of a crystalline liquid film wherein electric field has been properly selectively applied to these electrodes, thus selectively displaying a part of or the whole of the image, but it has never been tried to present a light and shade portion in the image or to display a plurality of colored images.

Generally, such a conventional electro-optical display device, electrical field is applied to electro-optical material by selecting one or both electrode of a pair of electrode which opposes through electro-optical material, and displaying character or simple figure.

Mr. Schulthess filed U.S. Pat. No. 3,774,195 before the filing date of original application of this application.

In this U.S. Pat. No. 3,774,195 electrode of electro-optical display device is divided into plurality of electrodes and blocking current is applied to said electrodes through control voltage circuit from electric source to be measured. Said control voltage circuit is constructed by standard voltage source, and plurality of standard resistors connected in series each other, and these resistors are elements of external voltage dividing circuit to produce step voltage gradient. Therefore, said standard resistors are elements of determination to flow or not said blocking current supplied from electric source to be measured, so that electric voltage is added to selected electrode only from said plurality of electrodes according to the value of voltage to be measured. Therefore principle of this

patent is same to prior known electro-optical display device having switching circuit for selecting electrode.

The present invention is to provide electro-optical display device based on different principle from said patent. In this invention, its electrode is divided into a plurality of parts, each electrode is connected at least one external impedance element in series, the impedance ratio between impedance of external impedance element and impedance between electrode in cell differs each other and produce voltage gradient in electrodes in cell, divided currents supplied from external AC electric source flow constantly in all of a plurality of said series circuit, characterized in that the voltage between each first electrode and second electrode differs each other.

SUMMARY OF THE INVENTION

In present invention, a plurality of closed circuit in which at least one of external impedance element and a pair of opposing electrode are connected in series, is provided, by changing impedance ratio between impedance of external impedance element and impedance between a pair of electrode potential between a pair of electrode differ in each closed circuit, thus enables to vary continuously the image produced by electro-optical effect due to the difference of impedance ratio between impedance of external impedance element and impedance between a pair of electrode by only changing the value of external AC voltage without employing electronic selecting element of electrode such as switching element which is inevitable in prior device.

Accordingly, it is the first object of present invention to provide an electro-optical device in which electrode of electro-optical device is divided into plurality of parts, the divided electrodes are connected to external AC voltage source through at least one of external impedance element, the impedance ratio between impedance of external impedance element and impedance between electrodes in cell differs each other, thus enables to change continuously the brightness or color tone of image produced by the ratio between impedance of external impedance element and impedance between a pair of electrode by changing the value of external AC voltage source without employing electronic or mechanical selecting means of plurality of electrode.

Second object of this invention is to provide an electro-optic device serviceable as an indoor or outdoor decorative display showing a very impressive image-up in which a display having various brightnesses and/or a plurality of color tones different stepwise from each other is carried out, and not only simple characters and figures but also intricate pictures and patterns having various brightnesses and/or color tones can be displayed.

Third object of the invention is to provide an electro-optic device in which a display having a plurality of color tones different stepwise from one another is carried out so as to provide a map for indicating various levels such as a golf course map, a map for informing of areas where photochemical smog occurs and a weather chart for indicating areas of "fine weather" and "rainy weather" by distinguishing them by brightness and/or colors.

Fourth object of the invention is to provide an electro-optic device which can be readily fabricated at a low cost and can take place of an advertisement tower

or neon sign board, in which a member for effecting an electro-optical action displays an image which varies with a delay time, or at time intervals, without the aid of an electrical RC timer circuit or mechanical switching operation.

Fifth object of the invention is to provide an electro-optic device which is suitable for a direction-indicating lamp of a vehicle, a passage guide board and an optically scanned light shutter such as an optical shade and a light blind.

Sixth object to the invention is to provide an electro-optic device which is utilized as an indicator for indicating a value of voltage or current, such as for instance an extremely thin ammeter or voltmeter and indicators in various instrument for measuring temperature, speed, weight, quantity of light, pressure and the like in combination with appropriate transducers.

Seventh object of the invention is to provide an electro-optic device which is useful as a volume indicator, or a level indicator, of an acoustical device and more particularly as an indicator for indicating right and left sounds in a stereophonic device or a tuning indicator in a communication device.

Eighth object of the invention is to provide an electro-optic device in which opposing electrodes in cell are parallel and construction is simple, enables to provide external impedance element at the surface or end of cell, to fabricate the device in small size and low cost.

Ninth object of the invention is to provide an electro-optic device which is possible to display moving image by adding square, or saw AC wave.

According to an aspect of this invention, the foregoing objects and other objects have been achieved by the presentation of an electro-optic device in which a plurality of electrodes different in area from one another are arranged in order and connected respectively through resistors or capacitors having the same value to a variable voltage source so that the threshold values of voltages to be applied to the electrodes for the occurrence of electro-optical phenomena in an electro-optical matter are different from one another or in which a plurality of electrodes having the same area are connected respectively through resistors or capacitors different in value from one another in order that voltages between the electrodes are different from one another.

According to an aspect of this invention, the foregoing objects and other objects have been achieved by the presentation of an electro-optic device in which a plurality of electrodes different in area from one another are arranged in order and connected respectively through resistors or capacitors having different in value from one another to a variable voltage source so that the threshold values of voltages to be applied to the electrodes for the occurrence of electro-optical phenomena in an electro-optical matter are different from one another or in which a plurality of electrodes having the same area are connected respectively through resistors or capacitors different in value from one another in order that voltages between the electrodes are different from one another.

According to a further aspect of the invention, the foregoing objects and other objects have been achieved by the provision of an electro-optic device formed in such a manner that it has a plurality of sections where the areas of opposed electrodes and the distances therebetween are different from one another and a plurality of electrodes provided respectively in the

sections are connected directly or through resistors or capacitors having different in value from one another to a variable voltage source so that the threshold values of voltage for presenting electro-optical phenomena of electro-optical matter in the sections, respectively.

The manner in which the foregoing objects and other objects of this invention have been achieved will become more apparent from the following detailed description and the appended claims when read in conjunction with the accompanying drawings, in which like parts are designated by like reference numerals or symbols.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a plan view illustrating one example of cell of this invention;

FIG. 2 is a cross-sectional view taken along line I — I in FIG. 1;

FIGS. 3 and 4 are plans view illustrating other examples of cell of this invention;

FIG. 5 is an equivalent circuit diagram of the example shown in FIGS. 1 and 2;

FIG. 6 is a graphical representation indicating the relationship between the light scattering wave length and the electric field strength;

FIG. 7 is a graphical representation indicating the relationship between the light scattering wave length and the electric field strength of the cell of twisted mode liquid crystal;

FIG. 8 is a graphical representation indicating the relationship between the light scattering wave length and the electric field of the cell of cholesteric crystalline liquid;

FIGS. 9 and 10 are equivalent circuit diagrams of other examples of the invention;

FIG. 11 is a plan view illustrating another example of cell in present invention;

FIG. 12 is a cross-sectional view taken along II — II line in FIG. 11;

FIGS. 13 and 15 are equivalent circuit diagrams of three examples in present invention;

FIG. 16 is a diagram for explaining the mode of operation of the arrangement shown in FIGS. 11 to 15;

FIG. 17 is a cross-sectional view of another example of cell in present invention;

FIG. 18 is an equivalent circuit diagram of the example shown in FIG. 17;

FIG. 19 is a cross-sectional view of another example of cell in present invention;

FIG. 20 is an equivalent circuit diagram of the example shown in FIG. 19;

FIG. 21 is a plan view illustrating another embodiment of the invention;

FIG. 22 is a cross-sectional diagram taken along line III — III in FIG. 21;

FIG. 23 is an equivalent circuit diagram of the embodiment shown in FIGS. 21 and 22;

FIG. 24 is a plan view illustrating another embodiment of the invention;

FIG. 25 is a sectional diagram taken along line IV — IV in FIG. 24;

FIG. 26 is a bottom view illustrating another embodiment of the invention;

FIG. 27 is a cross-sectional diagram taken along line V — V in FIG. 26;

FIG. 28 is a bottom view illustrating another embodiment of the invention;

FIG. 29 is a cross-sectional diagram taken along line VI — VI in FIG. 28;

FIGS. 30 to 35 are cross-sectional diagrams respectively illustrating various embodiments of the invention;

FIGS. 36 to 38 are block diagrams respectively illustrating different embodiments of the invention;

FIG. 39 is a circuit diagram illustrating the other embodiment of the invention;

FIG. 40 is a graphical representation indicating square wave for driving cell and characteristic curve of voltage of each electrode in cell shown in FIGS. 1 and 2;

FIG. 41 is a graphical representation indicating square AC wave for driving cell; and

FIGS. 42 to 44 show three examples of display by moving image of cell in present invention.

DETAILED DESCRIPTION OF THE INVENTION

With reference now to FIGS. 1 and 2, there is shown one example of the electro-optic cell according to this invention, which comprises a top substrate 1 made of transparent glass or resin under which first electrodes $a_1, a_2 \dots$ respectively having areas $S_{11}, S_{12} \dots$ different from one another are arranged and a bottom substrate 2 made of transparent glass or resin on which a second electrode is provided. The top substrate 1 is stacked on the bottom substrate 2 so that the first electrodes $a_1, a_2 \dots$ confront the second electrode b_1 , while an electro-optic material 3 is filled between them.

The first electrodes $a_1, a_2 \dots$ and the second electrode b_1 are formed by subjecting metals such as tin oxide and indium oxide or metallic compounds of these metals to various methods such as sputtering, vacuum evaporation and formation. The thickness of these electrodes is ordinarily on the order of from several hundreds to 2,000 Å. In this connection, in the case of forming an electro-optic cell of reflection type, the second electrode b_1 is formed as a light reflecting film by vacuum-evaporating or printing a metal such as aluminum, chromium, gold and silver on the bottom substrate 2. If required, the second electrode b_1 may be formed by laminating a plurality of these metals so as to increase the strength of the light reflecting film.

In this connection, organic crystalline liquids or artificial crystalline liquids, that is, crystalline liquids whose properties are changed electrically and optically that is, are electro-optically variable and which are artificially produced by dispersing non-organic fine particles or organic fine particles into solvents can be employed as the electro-optical material.

Nematic crystalline liquid matters such as listed below or mixture crystalline liquids containing two nematic crystalline liquid matters or more are available as the organic crystalline liquids:

Anisal-p-cyanoaniline, p-methylbenzal-p-buthylaniline, p-ethoxybenzal-p-cyanoaniline, p-cyanobenzal-p-buthylaniline, p-cyanobenzalanisidine, p-cyanobenzalphenetidine, 4'-cyanophenyl-4-n-buthylbenzoate, 4'-cyanophenyl-4-n-heptylbenzoate, ethyl-(p-anisalamino)-cinnamate, ethyl-p-(p-ethoxybenzalamino)-cinnamate, ethyl-(p-cyanobenzal)-cinnamate, n-buthyl-(anisal-p-amino)-cinnamate, isoamyl-(anisal-p-amino)-cinnamate, N-(4'-ethoxybenzal)-4-aminobenzonitrile, 4-(4'-n-hexylbenzalamino)-benzonitrile, 4-(4'-n-propylbenzalamino)-benzonitrile, p-azoxyanisole, 4-methoxy-4'-ethoxyazoxybenzene, anisal-p-aminophenylacetate, p-methoxybenzal-p'-n-

buthylaniline, p-methoxyformyloxybenzal-p'-n-buthylaniline, N-(p-methoxybenzal)-p-(2-propoxycarbonyl-1-propenyl)-aniline, p-ethoxybenzal-p'-n-buthylaniline, p-methoxy-p'-n-pentylcarbonyloxyazobenzene, p-ethoxy-p'-butoxycarbonylazobenzene, buthyl-p-(p-ethoxyphenoxycarbonyl)-phenylcarbonate, N-(4-methoxybenzal)-4'-O-n-buthylaminophenole, p-(p-ethoxyphenylazo)-phenylhexanoate, bis-(4-n-octyloxybenzal)-2-chlorophenylenediamine, 4,4'-bis-(hexyloxy)-azoxybenzene, 4,4'-bis-(heptyloxy)-azoxybenzene, 4-caproiloxybenzoic acid-4'-ethoxyphenyl ester, 4-caproiloxybenzoic acid-4'-butoxyphenyl ester, 4-n-propoxyphenyl-4'-n-propylbenzoate, 4-n-propoxyphenyl-4'-n-buthylbenzoate, 4-n-propylphenyl-4'-n-propoxybenzoate, 4-n-butoxyphenyl-4'-n-pentylbenzoate, 4-cyanophenyl-4'-n-buthylbenzoate, 4-buthylphenyl-4'-cyanobenzoate, 4-cyanophenyl-4'-hexylbenzoate, 4-cyanophenyl-4'-heptylbenzoate, 4-decyloxyphenyl-4'-buthylbenzoate, 4-pentyl-4'-cyanobiphenyl, 4-hexyl-4'-cyanobiphenyl, 4-heptyl-4'-cyanobiphenyl, 4-octyl-4'-cyanobiphenyl, 4-nonyl-4'-cyanobiphenyl, 4-propoxy-4'-cyanobiphenyl, 4-butoxy-4'-cyanobiphenyl, 4-pentoxyl-4'-cyanobiphenyl, 4-hexoxy-4'-cyanobiphenyl, 4-heptoxyl-4'-cyanobiphenyl, 4-octoxy-4'-cyanobiphenyl, 4-pentyl-4'-cyanotriphenyl, 4-hexyl-4'-cyanotriphenyl, 4-butoxy-4'-cyanotriphenyl, 4-pentoxyl-4'-cyanotriphenyl, 4-hexoxy-4'-cyanotriphenyl, 4-heptoxyl-4'-cyanotriphenyl, 4-octoxy-4'-cyanotriphenyl, and 4-nonyloxy-4'-cyanotriphenyl.

It is possible to add dye such as methyl-red, indophenol blue to produce guest host effect.

As will be described later, in some cases a mixture prepared by mixing a small amount of cholesteric crystalline liquid material in a nematic crystalline liquid material are employed as the electro-optical material, and sometimes a nematic crystalline liquid matter added with an dipole type additive is employed therefore. In addition, a mixture of alkoxyphenyl-acetylchloride, 4-alkylphenyl-acetylchloride and 4-acetoxyphe-

nyl-acetylchloride is employed and furthermore a nematic crystalline liquid matter mixed with a smectic crystalline liquid material is employed as the electro-optic matter.

Employed as the colloidal crystalline liquid are: colloidal suspension liquids prepared by dispersing in solvents such as water the organic or non-organic fine particles of, for instance, tungsten oxide, vanadium oxide, a needle-shaped non-homogenous crystal such as rock crystals, bismuth carbonate, lead crystal, herapathite, or polyvinylidene fluoride. These colloidal suspension liquids added with dipole type additives are used as the colloidal liquids.

It is possible to use material having electrochromic effect such as diheptil viologen bromide as other electro-optical material.

Furthermore, an organic crystalline liquid of field effect type made from two or more of the materials listed below can be employed as the electro-optical material: cholesterol bromide, cholesterol chloride, cholesterol iodide, cholesterol nitrate, cholesterol hexanoate, cholesterol oleate, cholesterol linoleate, cholesterol linolenate, cholesterol nonanoate, cholesterol decanoate, cholesterol laurate, oleyl cholesterol carbonate, 2-(ethyl-hexyl) cholesterol carbonate, heptyl cholesterol carbonate, octyl cholesterol carbonate, nonyl cholesterol carbonate, decyl cholesterol carbonate, 2-(methoxyethyl) cholesterol carbonate, methyl cho-

lesterol carbonate, buthyl cholesterol carbonate, and p-nonylphenyl cholesterol carbonate.

In some cases, suspensions of organic pigment can be used as the electro-optical material.

In addition, generally, the film of electro-optical material 3 is on the order of from several to 20 μm in thickness, forming a white or colored image in a considerably low electric field.

As is apparent from FIG. 2, the first electrodes a_1, a_2, \dots are connected respectively through external impedance element Z_1, Z_2, \dots each having the same impedance, to one terminal of an external variable voltage source E_d while the second electrode b_1 is connected to the other terminal of the external variable voltage source E_d . Thus the electric fields created between the respective first electrodes a_1, a_2, \dots and the second electrode b_1 for the purpose of creating the electro-optical phenomenon of the electro-optical material 3 filled therebetween are different from one another. This external variable voltage source E_d may be any alternating current or direct current variable voltage source. A light source (not shown) is positioned above the top substrate 1.

FIGS. 3 and 4 show other examples of cell having first electrodes of different shape and area.

The operation of this electro-optical cell will be described with referent to FIG. 5 which illustrates the equivalent circuit of the cell in the case of resistor R_1, R_2, \dots as impedance element Z_1, Z_2, \dots . In FIG. 5, reference symbols ra_1, ra_2, \dots are resistors existing between the respective first electrodes a_1, a_2, \dots and the second electrode b_1 . It is assumed that the ratio of the areas of the first electrodes a_1, a_2, \dots is 1:4:9.... The internal resistances between the respective first electrodes and the second electrode decrease with the increments of the areas of the first electrodes. Accordingly, $ra_1 > ra_2 > ra_3, \dots$. At the same time, the internal capacitances existing between the respective first electrodes and the second electrode become $ca_1 < ca_2 < ca_3, \dots$. The voltage division ratios of the resistances and capacitances $ra_1, ca_1; ra_2, ca_2; ra_3, ca_3, \dots$ with respect to the resistors r_1, R_2, \dots are successively increased. It accordingly follows that the electro-optic cell shows electro-optic phenomena with different tones at the successive electrodes a_1, a_2, \dots .

FIG. 6 illustrates the relationships between voltages (indicated on the ordinates) applied between the first and the second electrodes and light intensity ratios (indicated on the abscissas), in which reference symbols M and N indicate the characteristic curves of two kinds of nematic crystalline liquid materials. Accordingly, upon connection of the first electrodes and the second electrode to the voltage source, an electro-optic effect is produced in such a manner that the light intensity is gradually lowered in the order of the electrodes a_1, a_2, \dots , as a result of which an image having an optical tone of light and shade is formed.

FIG. 7 illustrates the relationship between voltage indicated on the ordinate applied between the first and the second electrode and transparency indicated on the abscissas in the cell of twisted mode liquid crystal. Curve M1 is a characteristic curve of device in which polarization directions of the two linear polarizing plates provided on the opposite sides of cell are parallel. Curve N1 is a characteristic curve of device in which polarization directions of the two linear polarizing plates provided on the opposite sides of cell are rectangular. As seen in FIG. 7, curve M1, N1 varies

rapidly by the variation of voltage so that it is possible to distinguish accurately the electro-optical effect.

FIG. 8 shows the relationships between electric field strengths and light scattering wave lengths in the case where a cholesteric crystalline liquid material of field-effect type consisting a mixture of the following substances is employed as the electro-optical material 3:

| | |
|--------------------------|---------------|
| cholesterin bromide | 45% by weight |
| nonyl phenyl cholesterol | 25% by weight |
| cholesterin oleate | 30% by weight |

In this case, an image having color tones different from one another is formed in the order of the first electrodes a_1, a_2, \dots .

In the above described example, the resistors R_1, R_2, \dots are employed. However, in the case where the voltage source is a.c., reactance elements such as capacitors may be employed instead of the resistors R_1, R_2, \dots . FIG. 9 shows an equivalent circuit arranged on the basis of this idea, in which capacitors C_1, C_2, \dots which are equal in capacitance to one another are employed instead of the resistors R_1, R_2, \dots respectively. FIG. 10 shows another embodiment of this invention in which resistors R_1, R_2, \dots and capacitors C_1, C_2, \dots are connected in parallel respectively. FIGS. 5, 9 and 10 are completely the same in function and operation.

EXAMPLE 1

In FIGS. 1 and 2, top substrate 1 and bottom substrate 2 are made of soda lime glass plate and first electrodes a_1, a_2, \dots are formed by vacuum evaporation of indium oxide of 500 Å thickness. Schiff type liquid crystal mixture i.e. DAINEX DNM-1 ($V_{th} = 6$ volt) is sandwiched in gap of 12 μm between said top and bottom substrate 1, 2 and its peripheral part is sealed by epoxy adhesive, and completed electro-optical cell.

In this example of the invention the values of resistance elements R_1, R_2, R_3 and R_4 are not critical, and will be selected to create a significant voltage division between the internal impedance in the cell and the resistance element or reactance element in series with this internal impedance.

Referring to FIG. 5, typical values of resistance elements R_1, R_2, R_3 and R_4 as compared with typical internal cell impedances (both resistance and reactance) are as follows:

| | | |
|--------------------|---------------------|-----------------|
| R_1 - 2.7 Megohm | ra_1 - 7.5 Megohm | Ca_1 - 53pF |
| R_2 - 2.7 Megohm | ra_2 - 4.8 Megohm | Ca_2 - 320pF |
| R_3 - 2.7 Megohm | ra_3 - 2.3 Megohm | Ca_3 - 960pF |
| R_4 - 2.7 Megohm | ra_4 - 1.2 Megohm | Ca_4 - 1800pF |

If voltage of variable voltage source E_d is varied from 10 volt to 25 volt at 32 Hz AC, first electrode a_1 operates at 10.8 volt, first electrodes a_1, a_2 operate at 12.5 volt, first electrodes a_1, a_2, a_3 operate at 17 volt, first electrodes a_1, a_2, a_3, a_4 operate at 25 volt.

EXAMPLE 2

Electro-optical cell is same to Example 1. Capacitors C_1, C_2, \dots are connected to said first electrodes as seen in FIG. 9. Each value of said capacitor C_1, C_2, C_3, C_4 is 3000pF respectively. If voltage of variable voltage source E_d is varied from 30 volt to 38 volt at 32 Hz AC, first electrode a_1, a_2, a_3, a_4 operate progressively.

In the embodiments of the electro-optical cells described with reference with FIGS. 1 to 5, 9, 10, the areas of the first electrodes $a_1, a_2 \dots$ are different stepwise from one another so as to change the internal resistances $ra_1, ra_2 \dots$ or capacitances $Ca_1, Ca_2 \dots$ between the first electrodes and the second electrode b_1 .

However, field strengths between the first electrodes $a_1, a_2 \dots$ and the second electrode b_1 may be varied by the following method. That is, the areas of the first electrodes $a_1, a_2 \dots$ are made the same, but the resistors $R_1, R_2, R_3 \dots$ or capacitors $C_1, C_2, C_3 \dots$ connected in the circuit between the first and second electrodes are made different stepwise in value.

Examples shown in FIGS. 11 to 15 are provided on the basis of the above-described idea. As is shown in FIG. 11, under the top substrate 1 there are provided first electrodes $a_{11}, a_{12} \dots$ whose areas are the same, and as seen in FIG. 12 these electrodes $a_{11}, a_{12} \dots$ are respectively connected to the terminals of impedance element $Z_{11}, Z_{12}, Z_{13}, Z_{14} \dots$ which are connected in series to a variable voltage source Ed_{10} . FIG. 13 illustrates the equivalent circuit of cell in the case of resistor $R_{11}, R_{12} \dots$ as impedance element $Z_{11}, Z_{12} \dots$.

EXAMPLE 3

Electro-optical cell is same to Example 1 except each first electrode $a_{11}, a_{12} \dots$ having same area and circuit is same to FIG. 13. Typical values of resistance elements $R_{11}, R_{12} \dots$ and resistors $ra_{11}, ra_{12} \dots$, capacitors $Ca_{11}, Ca_{12} \dots$ existing between the respective first electrodes $a_{11}, a_{12} \dots$ and second electrode b_{11} are as follows. In this case liquid crystal is biphenyl type liquid crystal mixture i.e. E-4 made by E MERCK ($V_{th} = 1.8$ volt).

| | | | |
|-----------------|--------|------------------------|--------------------|
| $R_{11} - 10$ | Megohm | $ra_{11} - 2.8$ Megohm | $Ca_{11} - 625$ pF |
| $R_{12} - 2$ | Megohm | $ra_{12} - 2.8$ Megohm | $Ca_{12} - 625$ pF |
| $R_{13} - 2.5$ | Megohm | $ra_{13} - 2.8$ Megohm | $Ca_{13} - 625$ pF |
| $R_{14} - 1.25$ | Megohm | $ra_{14} - 2.8$ Megohm | $Ca_{14} - 625$ pF |

In this case, if the variable voltage Ed_{10} increase from 11 volt to 37 volt at 32 Hz AC, first electrodes $a_{14}, a_{13}, a_{12}, a_{11}$ operate progressively.

EXAMPLE 4

FIG. 14 illustrates the equivalent circuit of cell in the case of capacitors $C_{11}, C_{12} \dots$ as impedance element $Z_{11}, Z_{12} \dots$. Electro-optical cell is same to Example 3.

Referring to FIG. 14, typical values of capacitors C_{11}, C_{12}, C_{13} and C_{14} as compared with internal resistances and reactances of the cell are given in the following table:

| | | |
|--------------------|------------------------|--------------------|
| $C_{11} - 500$ pF | $ra_{11} - 2.8$ Megohm | $Ca_{11} - 625$ pF |
| $C_{12} - 1000$ pF | $ra_{12} - 2.8$ Megohm | $Ca_{12} - 625$ pF |
| $C_{13} - 1500$ pF | $ra_{13} - 2.8$ Megohm | $Ca_{13} - 625$ pF |
| $C_{14} - 2000$ pF | $ra_{14} - 2.8$ Megohm | $Ca_{14} - 625$ pF |

In this case, if the voltage Ed_{10} increase from 10 volt 35 volt as 32 Hz AC, first electrodes $a_{14}, a_{13}, a_{12}, a_{11}$ operate progressively.

FIG. 15 shows another embodiment of this invention in which resistors $R_{11}, R_{12} \dots$ and $C_{11}, C_{12} \dots$ are connected in parallel respectively.

In this invention the areas of the first electrodes are different and external impedance elements connected to said first electrodes are also possible to be different.

In this embodiment, configuration of cell and circuit are same to FIGS. 1, 2, 3, 4, 5, 9 and 10. Therefore we will explain only values of resistors or capacitors using same symbols in corresponding Figures.

EXAMPLE 5

Resistors $R_1, R_2 \dots$ are employed as external impedance elements $Z_1, Z_2 \dots$. Electro-optical cell is same to Example 1 in which electro-optical material is Schiff-cyano type liquid crystal mixture i.e. LIXON7104, its threshold voltage is 3 volt. Circuit is same to FIG. 5, and its values are given in the following table.

| | | | | |
|-------------|--------|--------------|--------|------------------|
| $R_1 - 5$ | Megohm | $ra_1 - 20$ | Megohm | $Ca_1 - 100$ pF |
| $R_2 - 2.5$ | Megohm | $ra_2 - 5$ | Megohm | $Ca_2 - 400$ pF |
| $R_3 - 1.6$ | Megohm | $ra_3 - 2.2$ | Megohm | $Ca_3 - 900$ pF |
| $R_4 - 1.3$ | Megohm | $ra_4 - 1.3$ | Megohm | $Ca_4 - 1600$ pF |

In this case, if the voltage Ed increase from 5 volt to 8 volt as 32 Hz AC, first electrodes a_1, a_2, a_3, a_4 operate progressively.

EXAMPLE 6

Capacitors $C_1, C_2 \dots$ are employed as external impedance elements $Z_1, Z_2 \dots$. Electro-optical cell is same to Example 1 in which electro-optical material is biphenyl type liquid crystal mixture i.e. E-4 made by E MERCK, its threshold voltage is 1.8 volt. Circuit is same to FIG. 9 and its values are given in the following table.

| | | | |
|-----------------|--------------|--------|-----------------|
| $C_1 - 2154$ pF | $ra_1 - 20$ | Megohm | $Ca_1 - 100$ pF |
| $C_2 - 1436$ pF | $ra_2 - 10$ | Megohm | $Ca_2 - 200$ pF |
| $C_3 - 1234$ pF | $ra_3 - 5$ | Megohm | $Ca_3 - 400$ pF |
| $C_4 - 1150$ pF | $ra_4 - 2.5$ | Megohm | $Ca_4 - 800$ pF |

In this case, if the voltage increase from 4 volt to 18 volt at 32 Hz AC, first electrodes a_1, a_2, a_3, a_4 operate progressively.

As explained above, in present invention, potential gradient produced in first electrodes $a_0, a_1, a_2 \dots$ is shown as graph in FIG. 16, in which ordinate shows the position of first electrodes and abscissa shows voltage of each first electrode. The voltage of each first electrode differs each other and divided currents flow constantly through every first electrode.

The advantage of present invention is that the circuit is simple and possible to fabricate readily and low cost because said potential gradient is made by impedance ratio between impedance of external impedance element and impedance between first electrodes and second electrode in cell.

In present invention, it is possible to display many kind of image and applicate various display device by changing the area of electrode according to purpose.

In wrist watch or same other small instrument, it is very difficult to distinguish the operation of each electrode by changing its area because of small area of each electrode. However, in present invention, it is possible to distinguish the operation of each electrode by changing the values of external impedance element connected to each electrode respectively, thus enables to display small image in step wise accurately.

It requires external voltage of wide range for operating each electrode when the difference of area of each electrode is large. However, in present invention the range of the external voltage for operating each electrode become small by adjusting the values of external impedance elements.

In present invention, it is possible to compensate the impedance error between each first electrode and second electrode due to the error of area of each electrode or distance between first and second electrode in each image, by adjusting the values of external impedance elements.

In present invention, it is possible to display many kind of image and applicate various display device by changing the value of external impedance element.

In present invention, it is possible to display many kind of image by changing the area of electrode and value of external impedance element. In this case, it is the most useful.

FIGS. 17 and 18 show another embodiment of present invention. In this embodiment, the second electrode is divided into a plurality of parts, which oppose to said first electrodes respectively. The divided second electrodes b_{21} , b_{23} are connected to the other terminal of external variable voltage source E_d through impedance element Z_{21} and Z_{23} , other divided second electrodes b_{22} , b_{24} are connected to the other terminal of voltage source E_d directly. Said impedance elements Z_{21} , Z_{23} . . . compensate impedance elements Z_{11} , Z_{13} . . . respectively.

FIGS. 19 and 20 show another embodiment of present invention, in which the second electrode is divided into a plurality of parts in different boundary of first electrodes. First electrodes are connected to voltage source through external impedance elements Z_{41} , Z_{42} . . . and second electrodes are connected to voltage source through impedance elements Z_{51} , Z_{52} . . .

A further example of the electro-optical cell is shown in FIGS. 21 to 23. As is apparent from FIG. 21, the electro-optical cell comprises first electrodes a_{21} , a_{22} . . . provided under a top substrate 1, the first electrodes being different stepwise in area from each other, and second electrodes b_{21} and b_{22} on a back substrate 2 which respectively confront the first electrode a_{21} and a_{22} the first electrode a_{23} and a_{24} . As is shown in FIGS. 22 and 23, the first electrodes a_{22} and a_{23} are connected together, while the first electrodes a_{21} and a_{24} are connected to the terminals of a variable voltage source E_{d20} . As a result, resistances ra_{21} , ra_{22} . . . between the first electrodes and the second electrodes are connected in series to one another. As the electro-optical cell is thus organized, increase of the voltage of the variable voltage source E_{d20} causes it to show an electro-optic phenomenon in order beginning with the first electrode having the smallest area. This example is suitable to the case where the voltage of the variable voltage source E_{d20} is relatively high.

Shown in FIGS. 24 and 25 is another example of an electro-optical cell according to this invention, which comprises: first electrodes a_{31} , a_{32} . . . concentrically arranged under a top substrate 1; and a second electrode b_{31} provided on a bottom substrate 2, the second electrode being arranged to confront through an electro-optical material 3 the first electrodes.

In this example, the first electrodes a_{31} , a_{32} . . . are different stepwise in area. Accordingly, as was described with reference to FIGS. 5 and 9, for instance, if a voltage of a variable voltage source (not shown) is

applied between the first electrodes a_{31} , a_{32} . . . and the second electrode b_{31} through resistors or capacitors (not shown), an electro-optical phenomenon occurs with increase of the voltage of the variable voltage source beginning with the central part of the electro-optical cell.

One example of the reflection type electro-optical cell according to this invention is shown with the bottom view in FIGS. 26 and 27, which comprises first electrodes a_{41} , a_{42} . . . which are different stepwise in area from one another, the first electrodes being provided under a top substrate 1, a second electrode b_{41} of reflection type provided on a bottom substrate 2, and resistors R_{41} , R_{42} formed of thick film resistance material by means of, for instance, vacuum evaporation or printing, the number of the resistors being the same as that of the first electrodes. One terminal of each of the resistors R_{41} , R_{42} . . . is connected to one terminal of a variable voltage source E_{d40} while other terminals of the resistors are connected to the respective ends of the respective first electrodes a_{41} , a_{42} . . . , and the second electrode b_{41} is connected to the other terminal of the variable voltage source E_{d40} . An equivalent circuit connected to this reflection type electro-optical cell is the same as that shown in FIG. 5. In addition, the reflection type electro-optical cell is provided with a spacer 4 provided between the top substrate 1 and the bottom substrate 2.

A modification of the reflection type electro-optical cell shown in FIGS. 26 and 27 is shown in FIGS. 28 and 29 in which the resistors are replaced by capacitors. More specifically, in this modification, first electrode plates H_{41} , H_{42} . . . which are the same in number as that of the first electrodes a_{41} , a_{42} . . . are provided on the opposite side of the bottom substrate 2. These electrode plates are connected to the ends of the first electrodes a_{41} , a_{42} . . . , respectively. An insulating layer 5 of high dielectric value, such as a film of silicon dioxide, organic silicon compound, chromium oxide, germanium oxide, magnesium oxide, magnesium fluoride or the like, is provided over the bottom substrate. Over the insulating layer 5 there is provided a second electrode plate 6 the end part of which is connected to one terminal of a variable voltage source E_{d40} . The other terminal of the variable voltage source E_{d40} is connected to the end part of the second electrode b_{41} . An equivalent circuit connected to this reflection type electro-optical cell is the same as that shown in FIG. 9.

In the electro-optical cell shown in present invention, an electric field is applied between the first electrode and the second electrode so that the molecules of an electro-optical material such as a nematic crystalline liquid material are subjected to turbulence so as to create light scattering and thereby form a white image (or monochrome image), or, as in the case where an electro-optical material such as a cholesteric crystalline liquid material is employed, only the light having a particular wave length is selectively reflected. In other words a colored image is made so that the strengths of electric fields between the first and second electrodes are different from one another thereby changing the shape of an image on the electro-optical cell.

In this connection, the shape or configuration of the image can be changed by the following method. That is, under the fieldless condition between both electrodes when applicable, the longitudinal directions of the molecules in the electro-optical material are uniformly arranged on an electrode surface and the field strength

between the first and second electrodes is changed partially so that the molecular arrangement of the electro-optical material is changed. In this way, the shape of the image can be changed by the utilization of only the change in the molecular arrangement. In this case a pair of polarizing plates should be provided on both side of the electro-optical cell.

Shown in FIGS. 30 to 35 are electro-optical cells formed according to the above-described concept.

One of the electro-optical cells described above is shown in FIG. 30, which comprises a pair of linear polarizing plates 11 and 12 provided on the both sides of an electro-optical cell 10 shown in FIGS. 1 through 29. This electro-optical cell 10 further comprises: substrates 11a, 12a; linear polarizing films 11b and 12b; and protective films 11c and 12c for the linear polarizing films.

The functional operation of this electro-optical cell 10 will be described.

It is assumed that the electro-optical cell 10 as shown in FIGS. 1 to 29 is arranged between the linear polarizing plates 11 and 12. The electro-optical cell 10 in which the longitudinal direction of a molecule in an electro-optical matter is greatly different from the direction of a dipole thereof, and each molecule is uniformly arranged as a homeotropic phase in a direction perpendicular to an electrode surface under the fieldless conditions, shows an optical isotropy. When such an electro-optical cell 10 is arranged between the linear polarizing plates 11 and 12 formed cross nicol to each other, light from a light source 13 passes through the linear polarizing plate 11 and then the electro-optical cell 10 as it is, but it is blocked by the linear polarizing plate 12; that is, it will not reach an observer 14, and therefore anyone who stands near the observer will see it black. The term "cross-nicol" as used in this specification means that the polarization directions of the two polarizers are crossed with respect to each other. Now, if an electric field is applied between the first and second electrodes confronted in the electro-optical cell 10 and the field strength exceeds the threshold value of the electro-optical cell 10, the molecules of the electro-optical matter 3 gradually change the direction of dipoles to the direction of the electric field, as a result of which the arrangement of the molecules is twisted. In the region where the electric field strength is low, only the light having a wave length of, for instance, blue, green . . . red . . . blue, green . . . is selectively passed through. If the electric field strength is made somewhat higher, the condition of turbulent flow takes place with the molecules. As a result, the light of all wave lengths from the light source 13 passes through all of the linear polarizing plate 11, the electro-optical cell 10 and the linear polarizing plate 12 simultaneously and reaches the observer 14. Accordingly, if we see it standing at a position approximately in front of the observer, we can clearly see an image corresponding to the shape of the electrodes in the black background.

Furthermore, if an electro-optical cell 10 is formed in which an electro-optical material has the longitudinal direction of a molecule greatly different from the direction of a dipole, and under the fieldless conditions the molecules are uniformly arranged as a homogeneous phase horizontally with respect to an electrode surface, and the cell thus formed is arranged between two linear polarizing plates 11 and 12 formed cross nicol to each other; or if an electro-optical cell 10 is formed in which under the fieldless conditions all the molecules are

horizontally arranged with respect to the electrode surface and the molecules thus arranged as a homogeneous phase are made to have twist alignment in a helical state, being different by 90 degrees from each other in the opposite electrode surface, and the cell thus formed is arranged between two linear polarizing plates 11 and 12 whose polarization directions are in parallel with each other; the application of an electric field between the opposed electrodes causes the molecules of the electro-optical cell to have a state of turbulent flow and to thereby present an optical anisotropy. As a result, the observer can see a white image corresponding to the electrodes.

Furthermore, in the case where an electro-optical cell 10 having a helical structure is formed in such a manner that in its electro-optical matter 3 the longitudinal direction of a molecule is approximately the same as the direction of a dipole, under the fieldless conditions all the molecules being arranged horizontally with respect to an electrode surface, the arrangement of the molecules being homogeneously three-dimensionally slightly twisted so as to be different by 90° with respect to opposed electrode surfaces and the electro-optical cell 10 thus formed is arranged between two linear polarizing plates 11 and 12 whose polarization directions are in parallel with each other; it is not possible to cause the turbulent flow of molecules by the application of an electric field between the opposed electrodes; however, the action of the electric field changes the molecular arrangement of the electro-optical material 3 and therefore the observer can observe a white image as an image corresponding to the shape of the electrodes in the black background. If the polarization directions of the linear polarizing plates 11 and 12 are formed cross nicol to each other in the fieldless condition between the electrodes, the light of all wave lengths from the light source 13 reaches the observer side passing through the cell and both polarizers and when an electric field is applied between the electrodes, the molecular arrangement is changed, as a result of which the observer can observe a black image, as an image corresponding to the shape of the electrodes, in the white background.

Next, it is assumed that the electro-optical cell is arranged between the linear polarizing plates 11 and 12.

More specifically, as electro-optical cell 10 is formed in which in its electro-optical material 3 the longitudinal direction of a molecule is greatly different from the direction of a dipole component force and under the fieldless conditions the molecules are uniformly aligned as so homogeneous phase horizontally with respect to an electrode surface, and the electro-optical cell 10 thus formed is positioned between the linear polarizing plates 11 and 12 whose polarization directions are perpendicular to each other. Under these conditions, if an electric field is applied between the electrodes, it causes the turbulent flow of molecules in the electro-optical material 3, which shows an optical anisotropy. As a result, the observer can see a white image, as an image corresponding to the shape of the electrodes, in the black background.

Similarly as in the above case, an electro-optical cell 10 may be formed in which in its electro-optical material 3 the longitudinal direction of a molecule is greatly different from the direction of a dipole component force and under the fieldless conditions the molecules are aligned as so homogeneous phase horizontally to be

twisted with respect to an electrode surface, and the electro-optical cell 10 thus formed is positioned between two linear polarizing plates 11 and 12 whose polarization directions are in parallel with each other. Under these conditions, if an electric field is applied between the opposed electrodes, the observer can see a white image as an image corresponding to the shape of the electrodes.

In addition, in the case where an electro-optical cell 10 is formed in which in its electro-optical material 3 the longitudinal direction of a molecule is approximately the same as the direction of a dipole component force and under the fieldless conditions the molecules are aligned as so homogeneous phase horizontally with respect to an electrode surface, the molecular alignment directions differing by 90 degrees in the vicinity of the inner wall of substrates, and the electro-optical cell 10 thus formed is positioned between two linear polarizing plates 11 and 12 whose polarization directions are in parallel with each other; it is not possible to have the molecular turbulent flow in the electro-optical material 3 by the application of an electric field between the opposed electrodes; however, the action of the electric field changes the molecular alignment in the electro-optical material 3 as a result of which the observer can see a white image, as an image corresponding to the shape of the electrodes, in the black background.

In this connection, if the linear polarizing plates 11 and 12 are arranged so that their polarization directions form 90° thereby to form a cross nicol to each other, the molecular alignment in the electro-optical material 3 is changed by the application of an electric field between the opposed electrodes, as a result of which the observer can see a black image corresponding to the shape of the electrodes in the white background.

In the case where the molecules of an electro-optical material are regularly aligned under the fieldless conditions while the partial application of the different electric fields between the first and second electrodes cause the molecular turbulent current in the electro-optical material, as is shown in FIG. 31 a color filter 15 is provided between the electro-optical cell 10 and the linear polarizing plate 12 so that an image formed by the electrodes is colorful.

The functional operation of the electro-optical cell shown in FIG. 31 will be briefly described. When under the fieldless conditions the molecules of the electro-optical material 3 are regularly aligned and the electro-optical material 3 therefore shows an optical isotropy, the light from the light source 13 passes through the linear polarizing plate 11, the electro-optical cell 10 and the color filter 15, but cannot pass through the linear polarizing plate 12. Accordingly, what is seen by the observer 14 is black. Now, when an electric field is applied between the electrodes opposed to each other so as to cause the molecular turbulent flow in the electro-optical material 3, the electro-optical material 3 shows an optical anisotropy. As a result, the light from the light source 13 can pass through the linear polarizing plate 11, the electro-optical cell 10, the color filter 15 and the linear polarizing plate 12, thereby indicating a colorful image formed by the electrodes.

In the above described embodiment of this invention, the color filter 15 is provided between the electro-optical cell 10 and the linear polarizing plate 12. However, the color filter 15 may be provided between the elec-

tro-optical cell 10 and the linear polarizing plate 11. In addition, the color filter 15 can be provided on the left side of the linear polarizing plate 11. If necessary, a colored light source may be employed instead of the provision of the color filter 15. Furthermore, if it is dark on the observer side, the color filter 15 may be provided on the side facing to the observer. The polarizing plates are not limited to the linear polarizing plates only, that is, other type polarizing plates can be employed as the polarizing plates.

Another example of the invention is shown in FIG. 32, in which an electro-optical cell 10, a linear polarizing plate 12 and a colored linear polarizing plate 16 which serves as both a color filter and a linear polarizing plate and is provided instead of the color filter are combined so as to display a colorful image. In this colored linear polarizing plate 16, a colored linear polarizing film 16b is formed over one surface of its substrate 16a. Furthermore, a protective film 16c is formed over the colored linear polarizing film 16b.

Shown in FIG. 33 is another embodiment of the invention which comprises a compound colored linear polarizing plate 17, an electro-optical cell 10 and a linear polarizing plate 12. The compound colored linear polarizing plate 17 is provided with colored linear polarizing films 17b and 17c formed on both sides of its substrate 17a. The compound colored linear polarizing films 17b and 17c are protected by protective films 17d and 17e, respectively. In this example shown in FIG. 33, the optical axes of the compound colored linear polarizing films 17b and 17c are intersected perpendicularly to each other, and when no electric field is applied to the cell the observer can see a particular color on the whole surface. Then, when an electric field is applied to the electro-optical cell 10, a single color image but different from that appearing in the case when no electric field is applied appears when the electric field is high.

Shown in FIG. 34 is one modification of the electro-optical cell shown in FIG. 31, in which a light reflecting layer 18 is provided on one side of the polarizing plate 11. This is a reflection type electro-optical cell.

Shown in FIG. 35 is one modification of the electro-optical cell shown in FIG. 32, in which a light reflecting layer 18 is provided on one side of the colored polarizing plate 16. This is a reflection type electro-optical cell, too.

Illustrated in FIG. 36 is a block diagram illustrating a device in which the electro-optical cell as described above is employed as an instrument for indicating analog data of a tachometer, a thermometer, a pressure gauge, or a photometer. The device shown in FIG. 36 comprises: a detector 20 for detecting temperature, weight, intensity of radiation, and the like; a transducer 21 for converting an output from the detector 20 into an electrical signal and an amplifier 22 for applying an output from the transducer 21 to the first and second electrode of the electro-optical cell 23 as described previously. The signal data indicating instrument can be formed considerably thin since it is constituted only by the electro-optical cell 23 which is relatively thin and the electrical circuit provided for the cell.

Shown in FIG. 37 is a device for comparing and displaying two analog data, such as right and left signals produced from a stereophonic device by employing the electro-optical cell 24 according to the present invention. The first electrodes thereof are divided into, for instance, two groups. The device comprises: detectors

25 and 26 for detecting two analog data; and amplifiers 27 and 28 provided for the detectors 25 and 26 respectively, the amplifiers applying their outputs between the first and second electrode of each group in the electro-optical cell described above.

With reference to FIG. 38, there is shown a device which employs the above-described electro-optical cell 30 for the purpose of detecting the fact that the output voltage of a voltage source 29 reaches a predetermined level, the output voltage being applied to the electro-optical cell 30 through a variable resistor 32 provided with a suitable control device 31.

FIG. 39 illustrates a device which employs the above-described cell for the indication of transmission time of a telephone service. The device shown in FIG. 39 comprises: a telephone set 33; a pick-up coil 34 for detecting the electrical level of the transmission circuit; and an amplifier 35 provided for the output of the pick-up coil 34, the amplifier 35 applying its output to the gate of a thyristor 36. The thyristor 36 is connected to a timer circuit consisting of a resistor 39 and capacitor 40 through a contact S_4 of a switch 38. The switch is set on when the receiver, or handset 37, of the telephone set 33 is unhooked. The device is further provided with a power source 41. A normally closed contact S_5 of the switch 38 is connected to a discharge resistor 42 of the capacitor 40. Both terminal of the capacitor 40 are connected to a voltage indicator 43 comprising an electro-optical material.

The operation of this device is as follows: Upon unhooking the handset 37 of the telephone set 33, the contact S_4 is closed. Under these conditions, the dial is turned and a person called unhooks the handset of his telephone set, thus completing the transmission circuit. As a result, the electrical level of the transmission circuit is changed, and the change of the electrical level is detected by the pick-up coil 34. The detecting output of the pick-up coil 34 is amplified by the amplifier 35 whereby the thyristor 36 is turned conductive. Accordingly, charging the capacitor 40 is started and the potential across the terminals of the capacitor 40 gradually increases. As a result, the electrodes of the voltage indicator 43 show electro-optical phenomena beginning with the electrode whose external input voltage necessary for showing an electro-optical phenomenon is the lowest, thereby indicating the lapse of a transmission time. In this connection, the electrical level of the transmission circuit may be detected by connecting the pick-up coil directly to the telephone set 33.

It is possible to display moving image changing periodically according to driving voltage in electro-optical cell shown in FIGS. 1, 3, 4, operating low frequency AC voltage less than few Hz. In this case configuration of wave of said driving AC voltage may be rectangular, square, saw, sine, triangular. For example, if said cell shown in FIG. 1 is driven square AC wave P_1 shown in FIG. 40, the voltage $e_1, e_2 \dots$ of each first electrodes $a_1, a_2 \dots$ will rise along the characteristic curve as shown in FIG. 40, and reach to threshold voltage V_{th} at $t_1, t_2 \dots$ in stepwise with time delay. Therefore first electrode $a_1, a_2 \dots$ exhibit electro-optical effect in stepwise with time delay without employing complicate circuit such as RC timer circuit. At the rest interval of said square AC wave P_1 , the voltage $e_1, e_2 \dots$ of each electrode $a_1, a_2 \dots$ decrease and reach to threshold voltage V_{th} at $t_{11}, t_{12} \dots$ and electro-optical effect of each electrode a_4, a_3, a_2, a_1 disappear in stepwise with time delay. Next we explain example of present inven-

tion in which cell is driven by square AC voltage source.

EXAMPLE 7

5 Cell and circuit are same to Example 5. Driving voltage E_d is 8 volt 1 Hz square AC wave, duty; 50%. First electrodes $a_1, a_2 \dots$ operate stepwise with time delay visually.

When said cell is to drive by square AC wave, square AC wave PQ shown in FIG. 41 which peak value is less than V_{th} , is applied to first and second electrode respectively, and phase difference between wave PQ is zero when no electro-optical effect occurs, and is half cycle when electro-optical effect occurs.

15 When said cell is driven by saw AC wave, it is possible to display moving image as well as cell is driven by square AC wave, but displaying period of each electrode $a_1, a_2 \dots$ will be different.

When said cell is driven by sine or triangular AC wave, it is possible to display moving image as well as cell is driven by square or saw AC wave, although displaying period of each electrode delays than cell is driven by square wave. Therefore square AC wave is preferable than sine or triangular AC wave for driving said cell. By said effect, it is possible to show moving display such as indicator of automobile, second display of watch or clock as shown in FIG. 42 or wrist watch as shown FIG. 43, level rising in cup by beer pouring as shown FIG. 44.

30 We claim:

1. An electro-optic device comprising a first transparent substrate, a second substrate juxtaposed to the first substrate, a body of electro-optically variable liquid disposed between said substrates, a plurality of first electrodes disposed on the surface of the first substrate facing the second substrate, each individual one of said plurality of first electrodes having an area different from the area of the others, a second electrode provided on the surface of the second substrate facing the first substrate, said liquid interposing internal impedance between said first electrodes and said second electrode, and a plurality of impedance elements external to said substrates and liquid, the impedances of different ones of said impedance elements being different from each other; each of said first electrodes being connected through a respective one of said impedance elements to a terminal of a voltage source, and said second electrode being connected to another terminal of the voltage source, so that there are a plurality of parallel circuits each comprising a respective one of said impedance elements in series with the respective internal impedance between a respective one of said first electrodes and said second electrode, whereby in each of said parallel circuits a first part of the voltage supplied from the voltage source exists across the respective internal impedance and a second part of the voltage from the voltage source exists across the respective impedance element, the ratios of the first part to the second part of the voltage being different at the different respective parallel circuits.

2. An electro-optic device comprising

- a single external electrical source,
- an electro-optical cell having a plurality of first electrodes and a second electrode opposing each other through electro-optical material,
- external impedance elements of same number as the number of said first electrodes,

- d. said first electrodes being connected in series to an end of each of respective ones of said external impedance elements, the values of said external impedance elements differing from each other,
- e. the other ends of said external impedance elements being connected together so as to be at the same potential and being connected to one end of said external electric source,
- f. the other end of the said external electric source being connected to the second electrode, thereby forming a plurality of parallel series circuits each of which comprises said external electric source, one of said external impedance elements, one of said first electrodes, the electro-optical material and said second electrode,
- g. Characterized in that the impedance values of said external impedance elements and the electro-optical material between said first electrodes and second electrode are related so that the values of divided currents supplied from said external source and flowing constantly in said series circuits respectively differ from each other.

3. An electro-optic device as claimed in claim 2, in which said first electrodes have areas which are different from each other.

4. An electro-optic device as claimed in claim 6 in which said first electrodes have equal areas.

5. An electro-optic device as claimed in claim 3, in which said external impedance elements are resistors.

6. An electro-optic device as claimed in claim 3, in which said external impedance elements are condensers.

7. An electro-optic device as claimed in claim 4, in which said external impedance elements are resistors.

8. An electro-optic device as claimed in claim 4, in which said external impedance elements are condensers.

9. An electro-optic device as claimed in claim 2, in which said external electric source provides a square AC voltage wave.

10. An electro-optic device as claimed in claim 3, in which said external electric source provides a square AC voltage wave.

11. An electro-optic device as claimed in claim 4, in which said external electric source provides a square AC voltage wave.

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